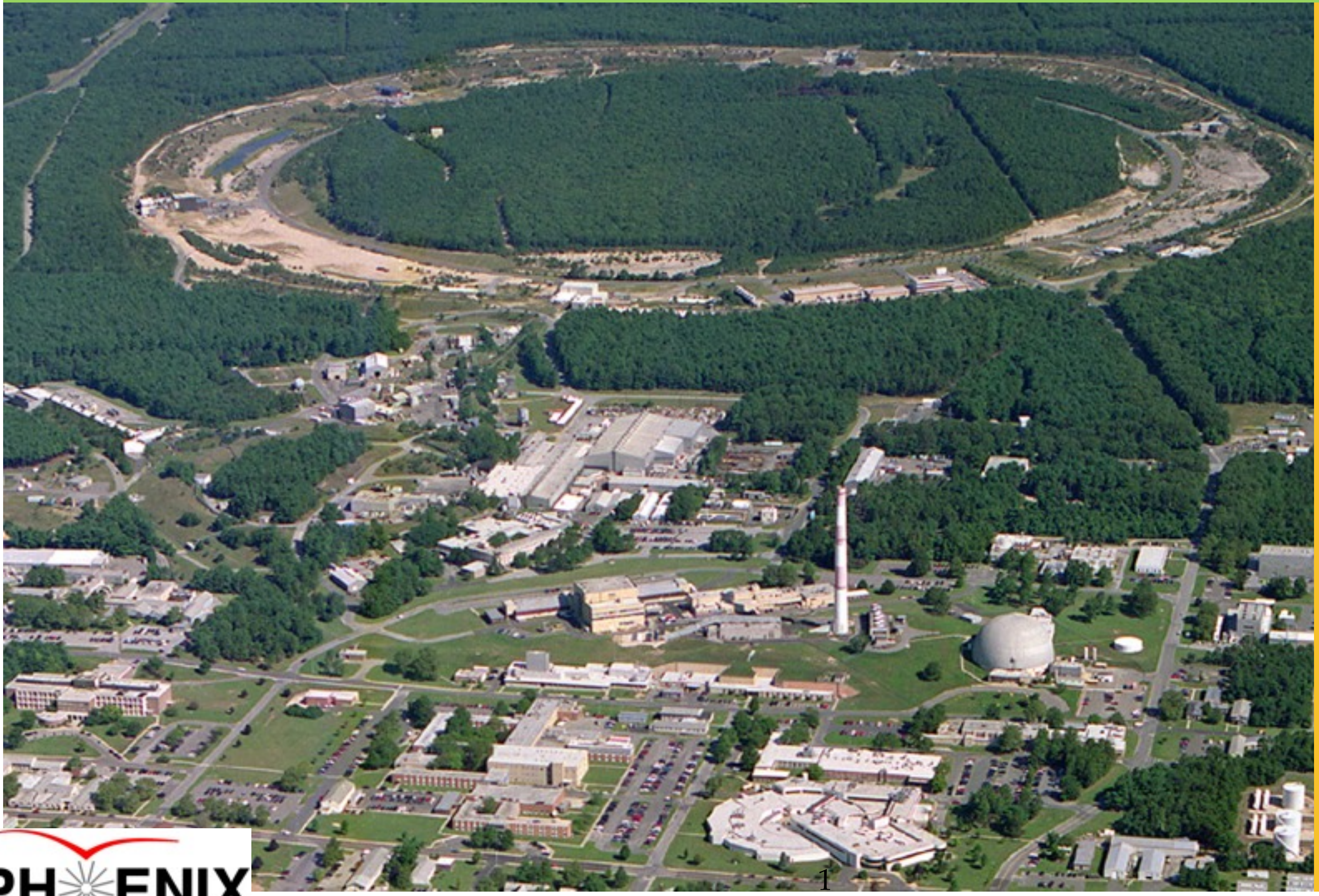
A new forward spectrometer for PHENIX

SPIN 2012, Dubna, Russia

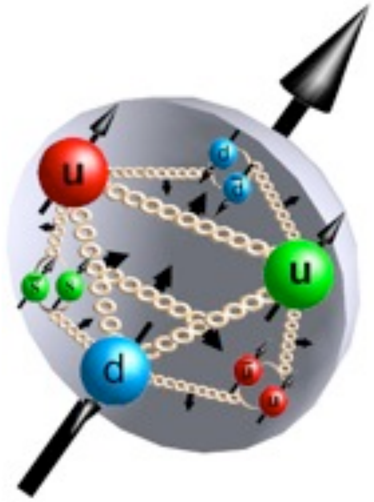
Francesca Giordano
for the PHENIX collaboration



PHENIX

The proton spin structure:

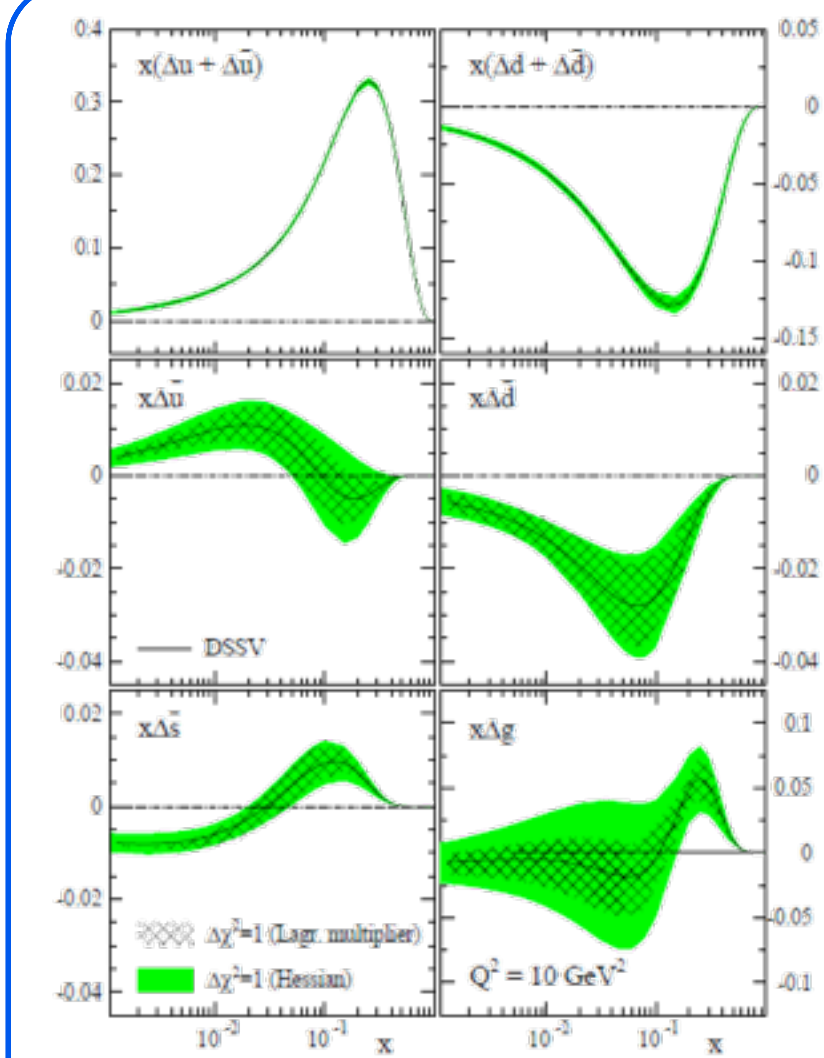
Spin crisis



quark spins — gluon spins — quark&gluon orbital motion

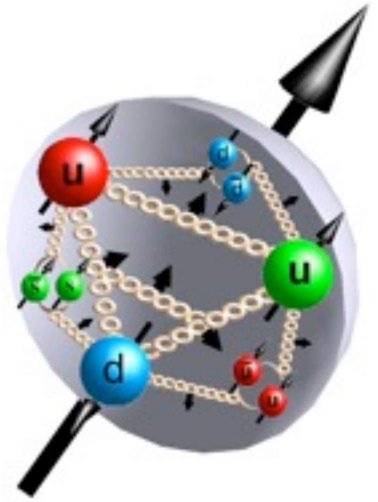
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

Δu_v Δd_v Δq_{sea}



DSSV arXiv:0904.3821

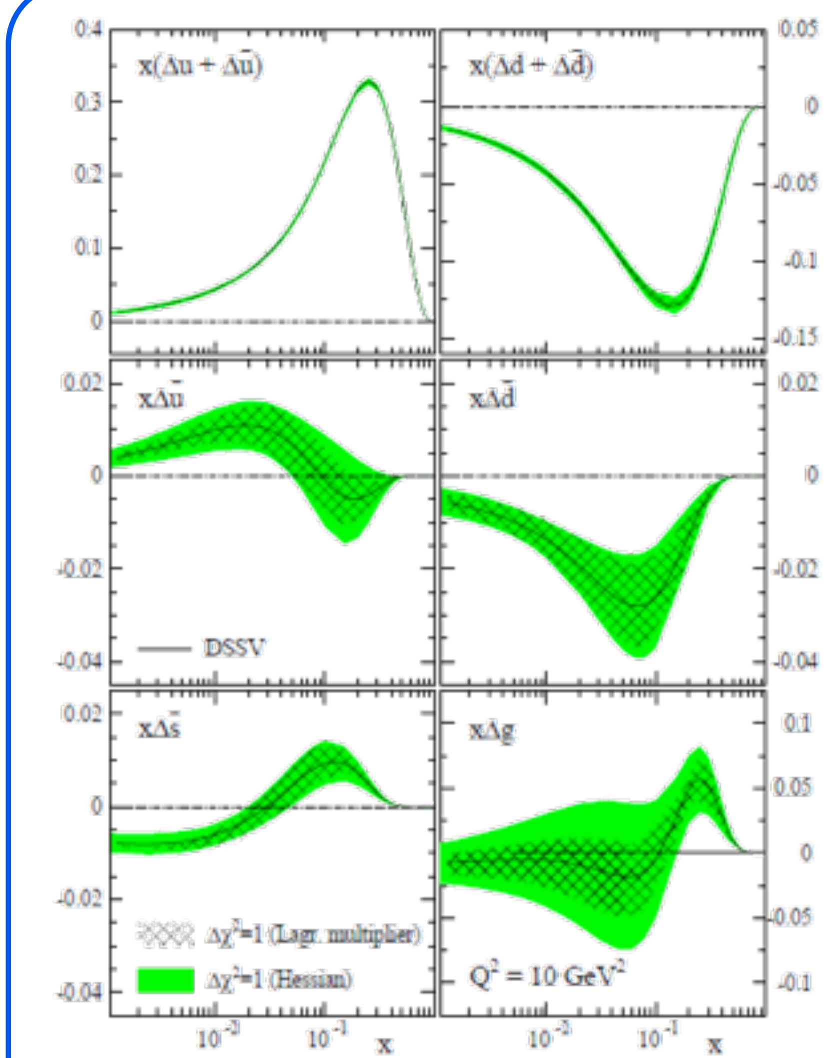
The proton spin structure:
Spin crisis



quark spins, gluon spins, quark&gluon orbital motion

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

$$\Delta\Sigma: \quad \Delta u_v \quad \Delta d_v \quad \Delta q_{sea}$$



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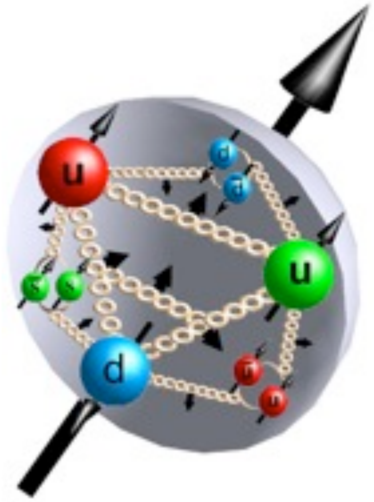
First spin crisis:

quarks only provide ≈ 30% of the proton spin

The proton spin structure:

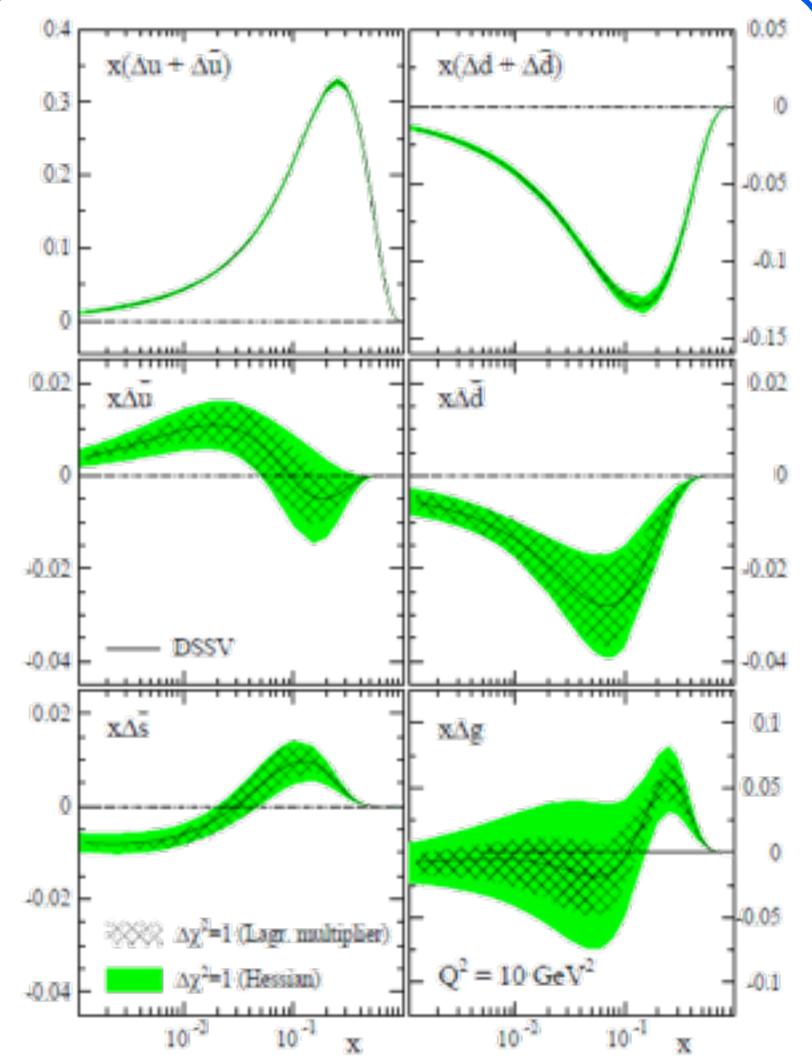
Spin crisis



quark spins — gluon spins — quark&gluon orbital motion

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

$$\Delta\Sigma \rightarrow \Delta u_v,\quad \Delta d_v,\quad \Delta q_{sea}$$



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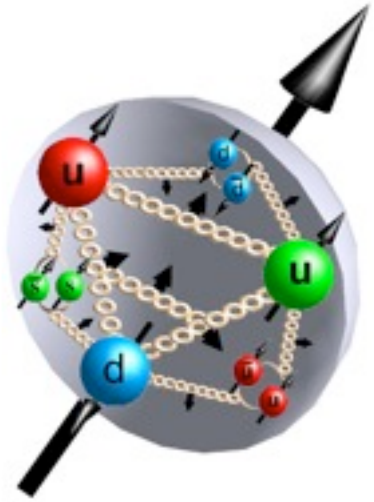
First spin crisis:

quarks only provide ≈ 30% of the proton spin

Where is the rest of the proton spin?

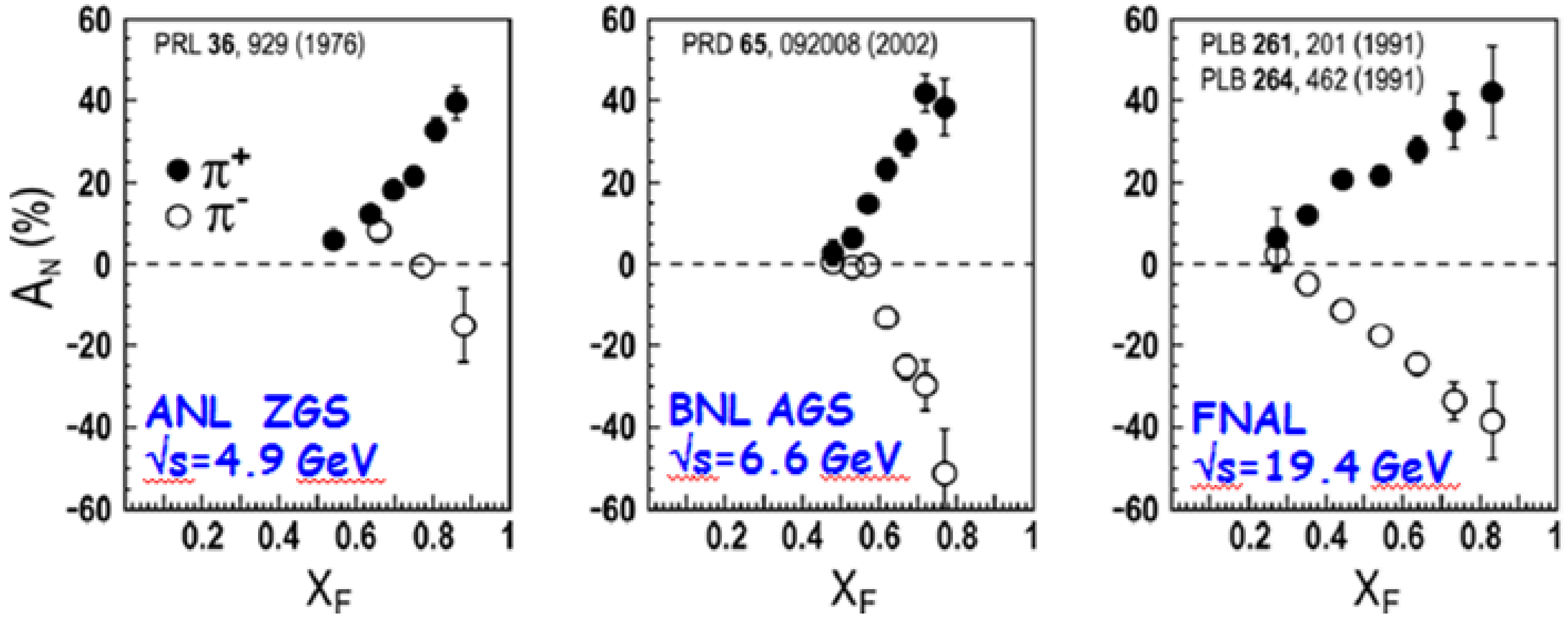
The proton spin structure:

Spin crisis 1.1



A_N predicted to be small by collinear pQCD

$$A_N \approx \frac{m_q \alpha_s}{p_T}$$



Second spin crisis:

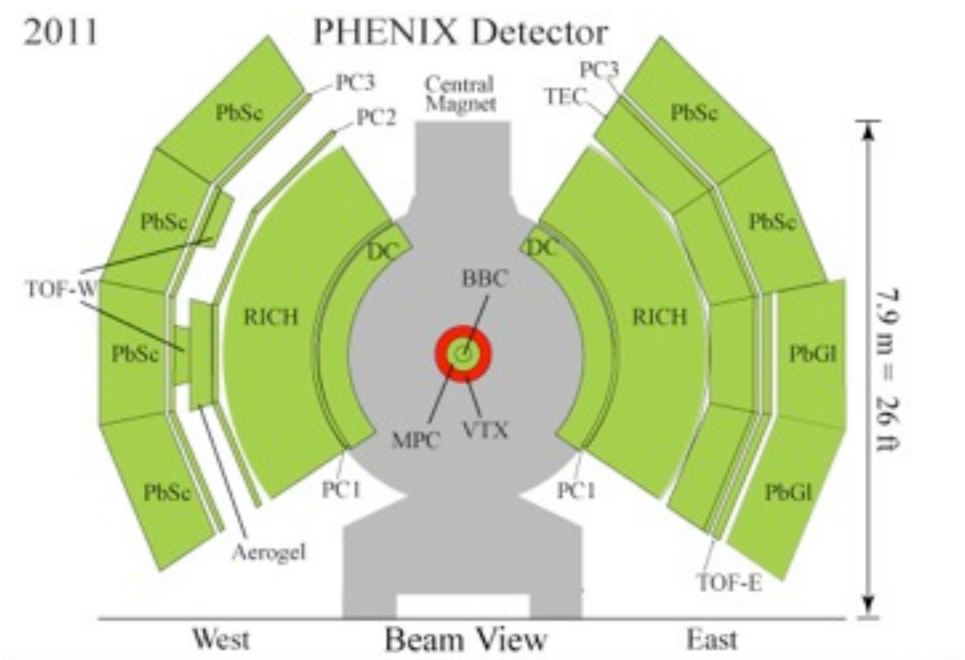
transverse effect not small!

… PHENIX so far …

PHENIX

Central Arms:

$$|\eta| < 0.35$$



Tracking, Momentum and PID for:
- ☆charged and neutral hadrons
- ☆direct photons
- ☆e+e-

PHENIX

Central Arms:

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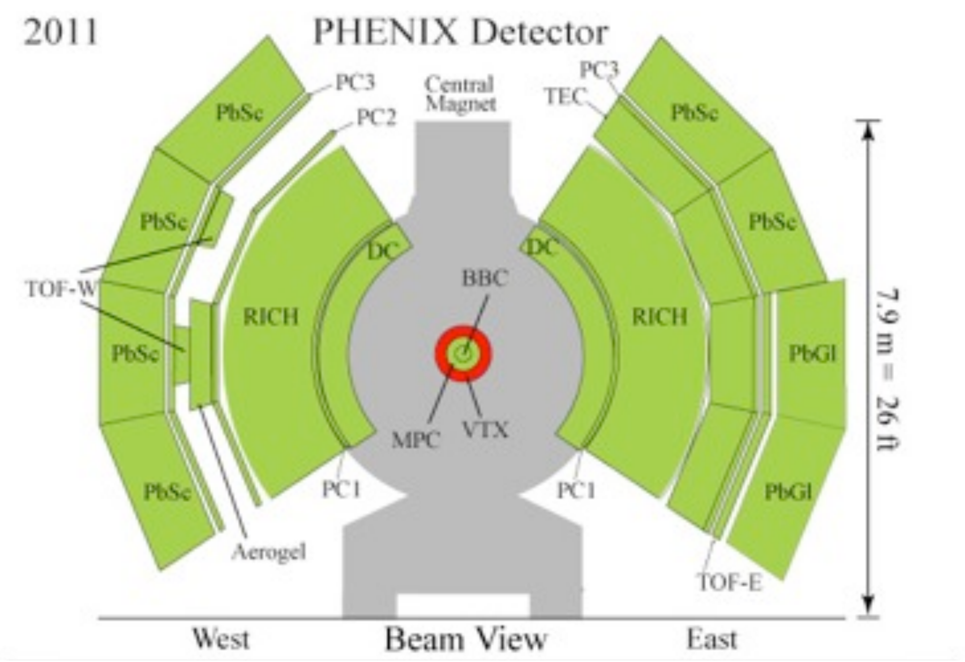

Tracking, Momentum and PID fo:

- ☆charged and neutral hadrons
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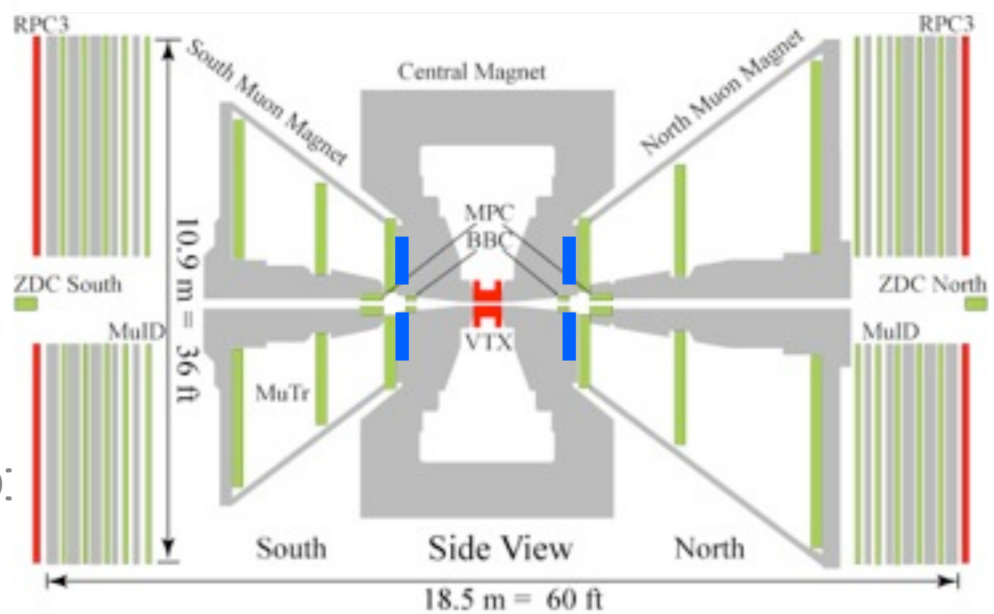
Forward Arms:

$$1.2 < |\eta| < 2.4$$

Tracking and Momentum for:

- ☆ $\mu^{\pm}$



PHENIX

Central Arms:

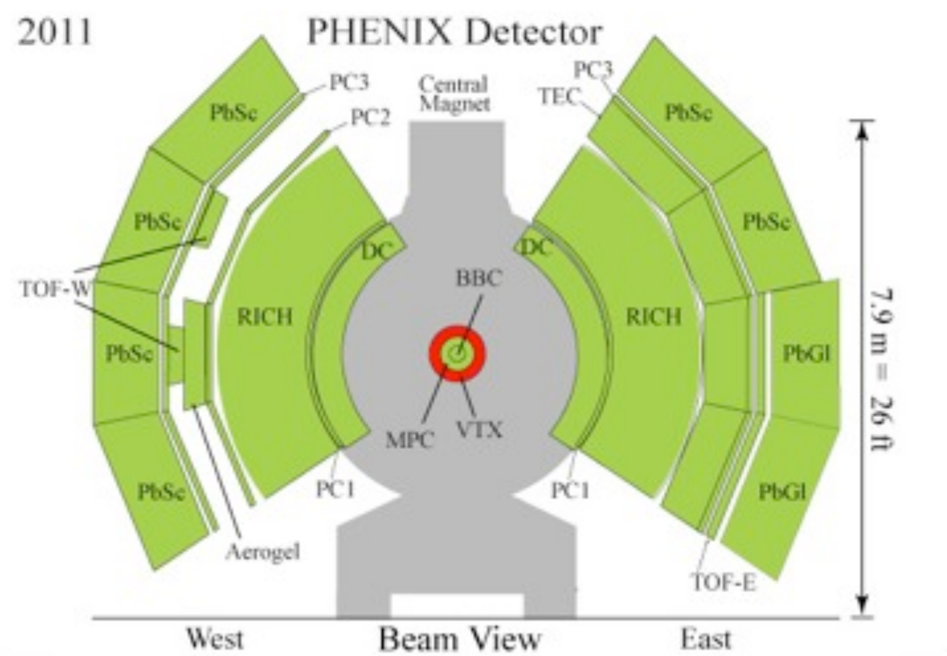
$$|\eta| < 0.35$$

Forward Arms:

$$1.2 < |\eta| < 2.4$$

Even more forward: MPC

$$3.1 < |\eta| < 3.9$$

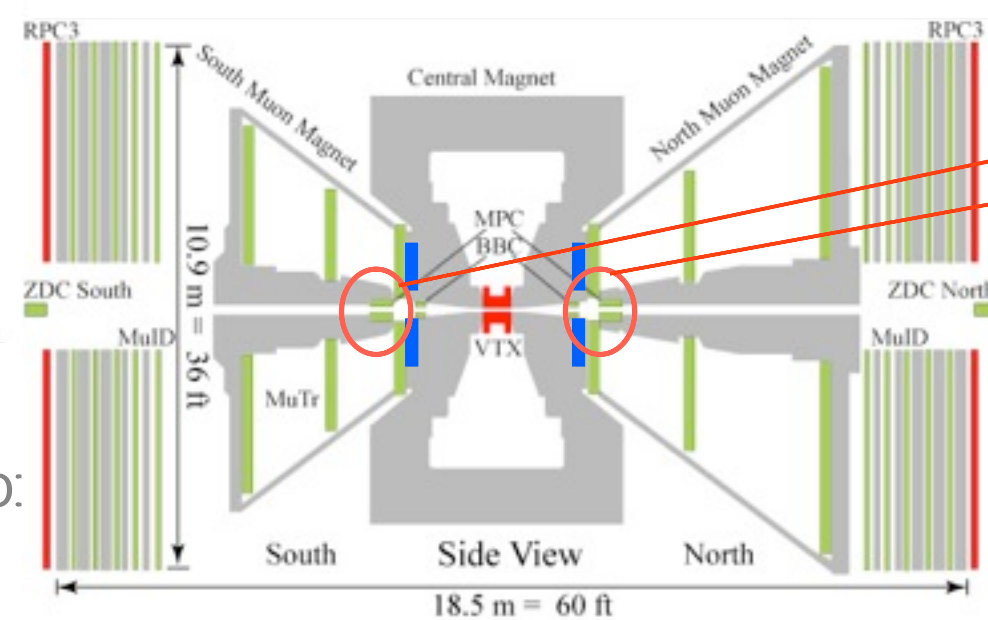


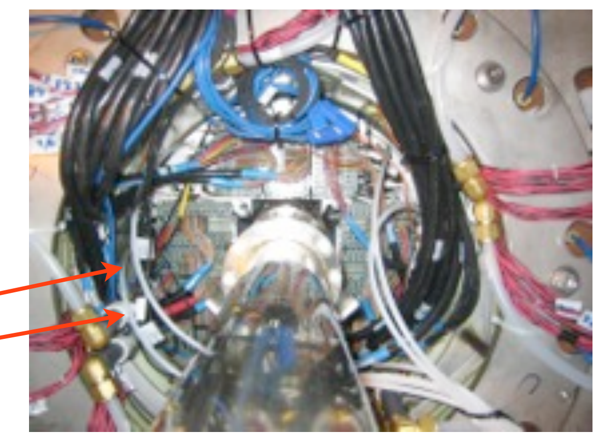
Tracking and Momentum for:

☆ $\mu^{\pm}$

γ_0

$\pi^0 \rightarrow \gamma\gamma$





Tracking, Momentum and PID fo:

☆charged and neutral hadrons

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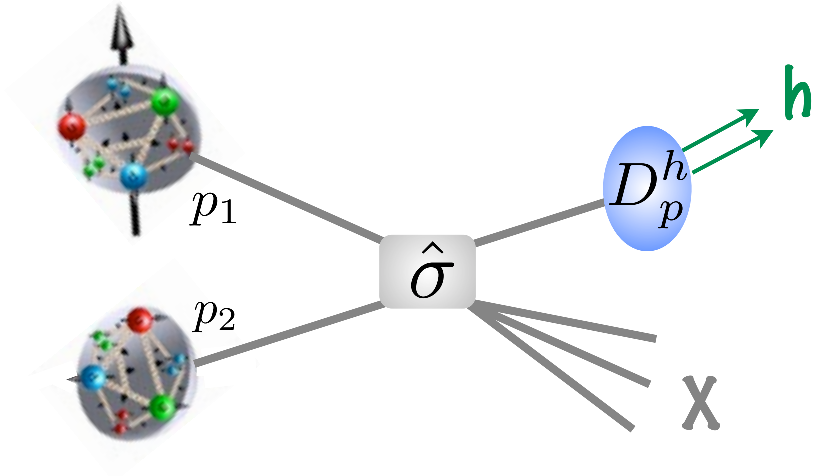
☆e+e-

Transverse Single Spin Asymmetries



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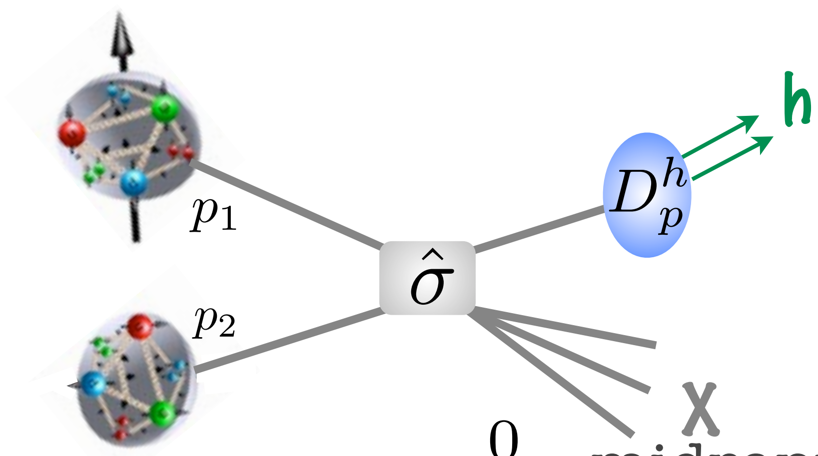
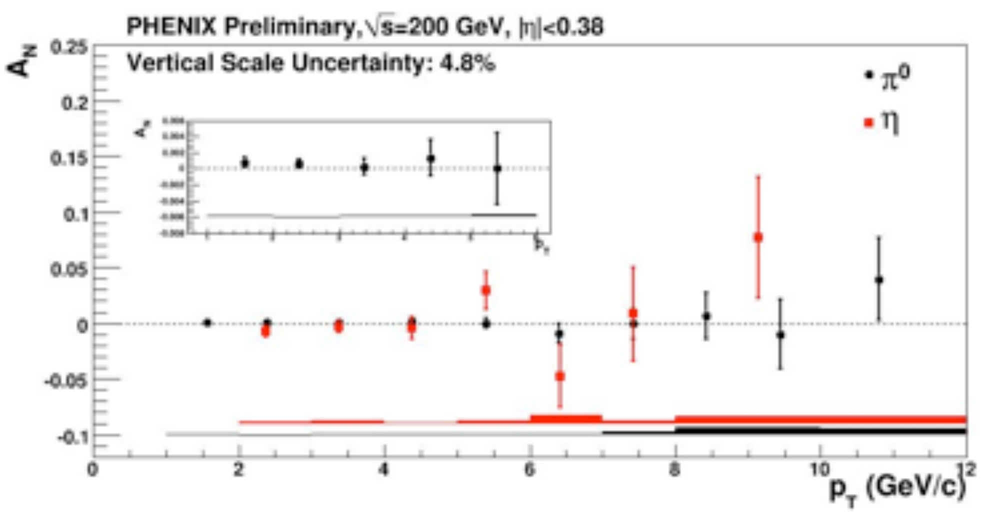
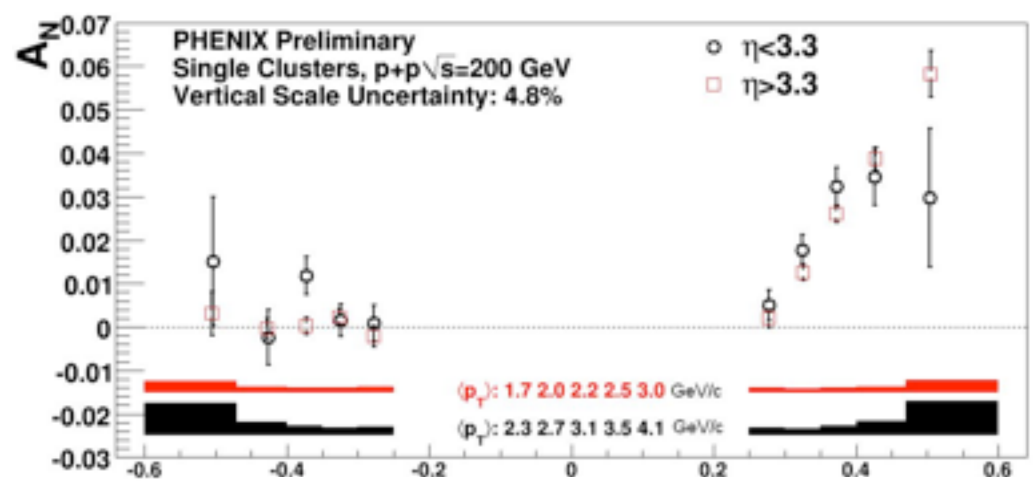
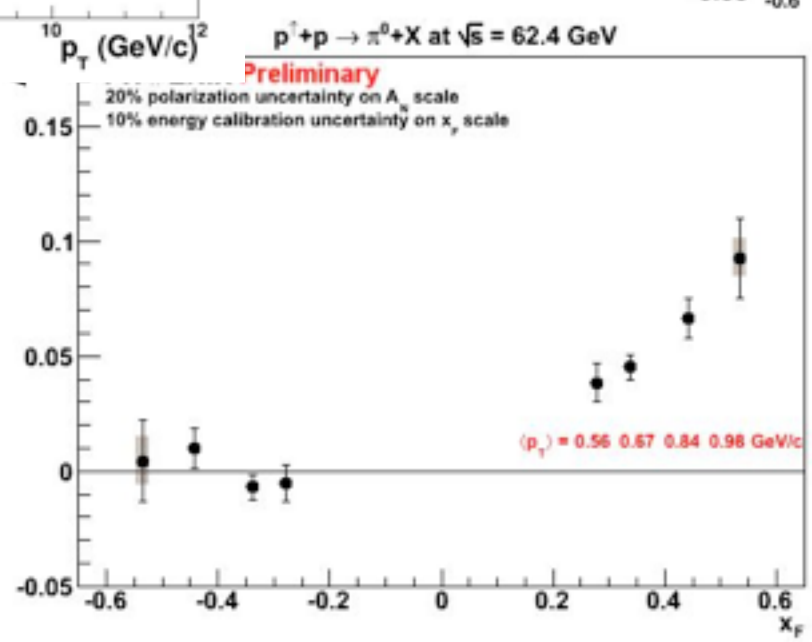
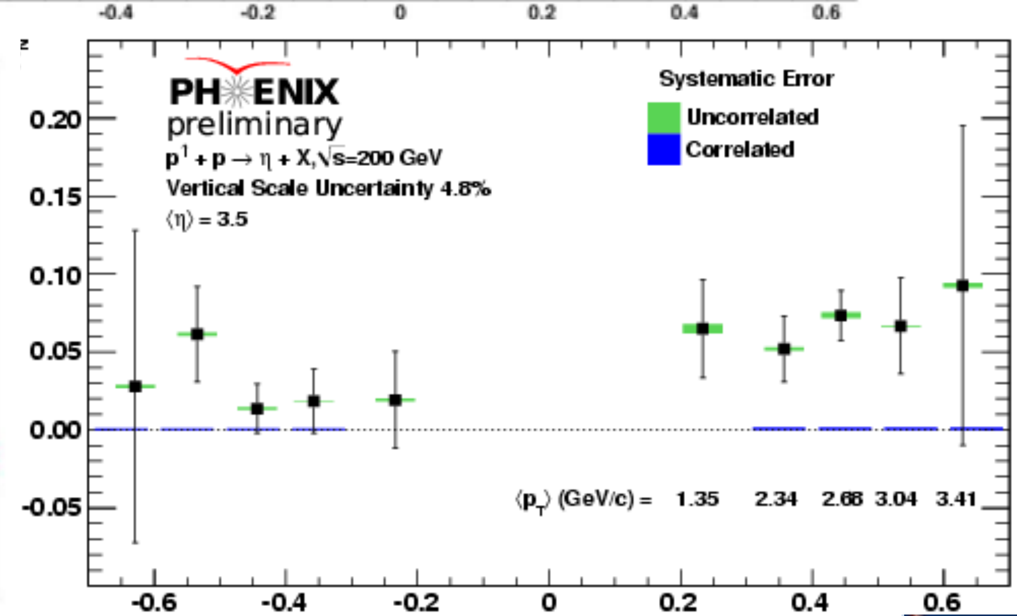


π^0 midrapidities









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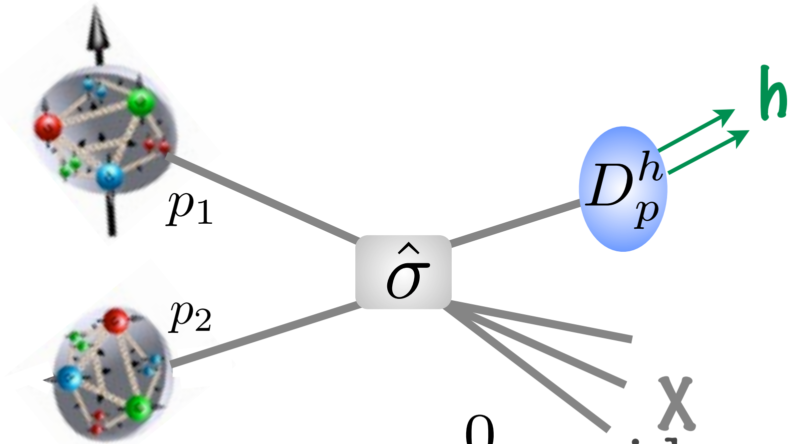

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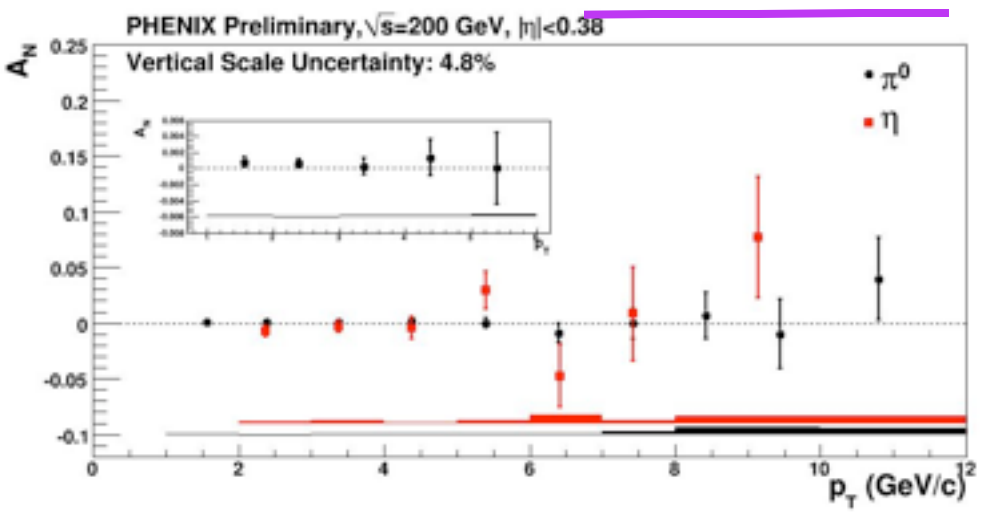
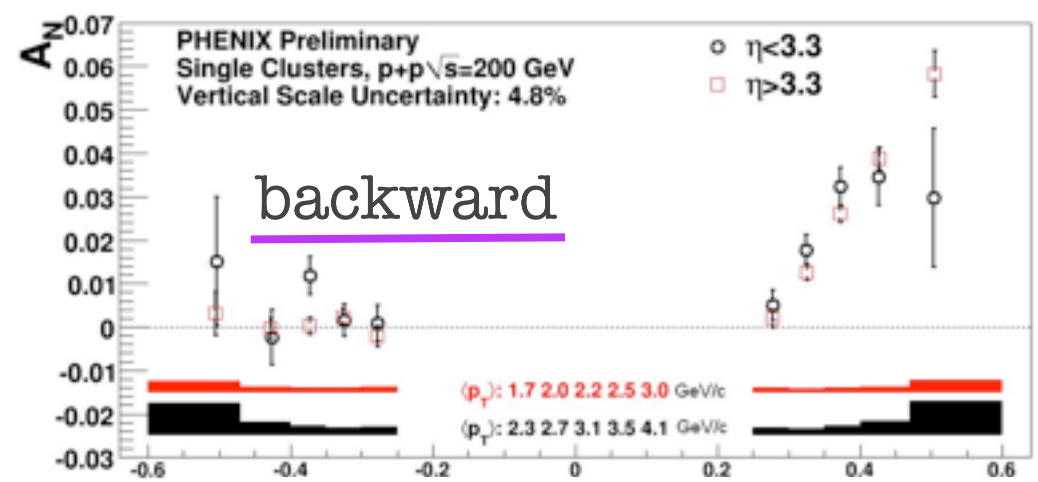
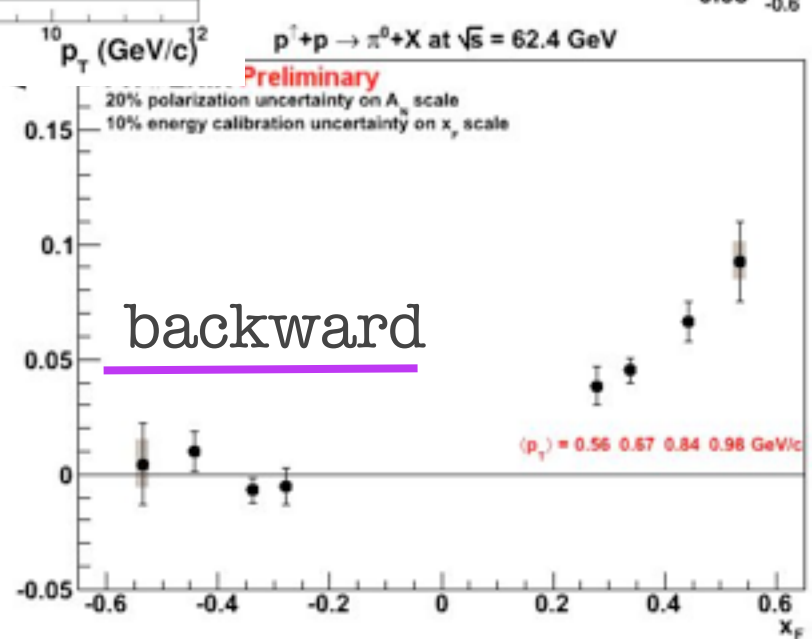


backward

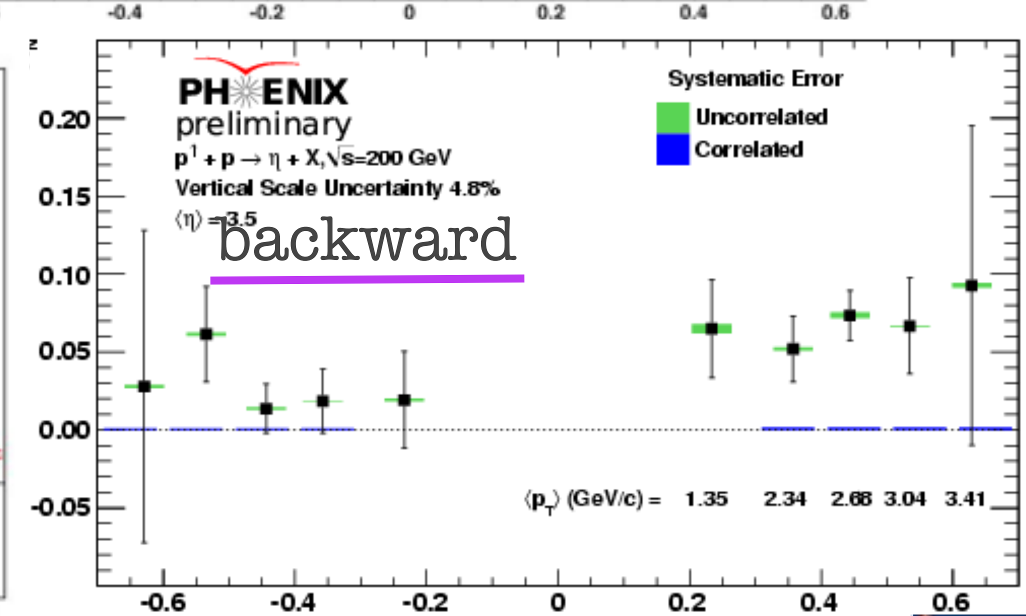


Zero asymmetry in the midrapidity and backward regions

backward



backward



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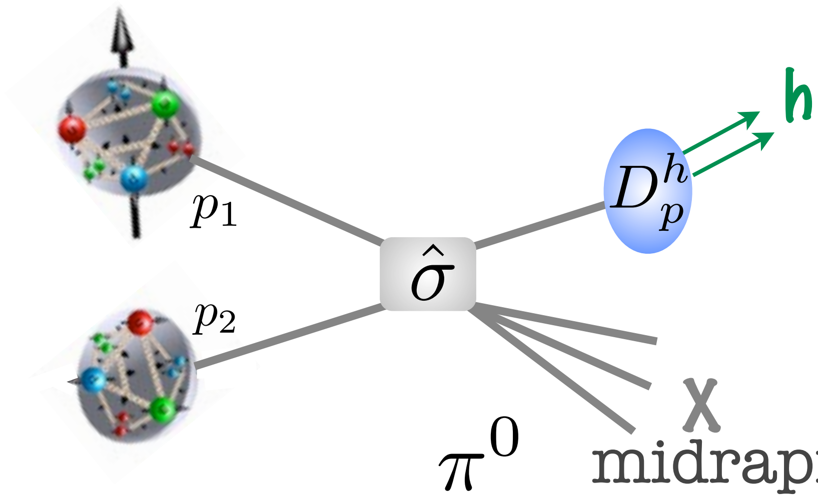
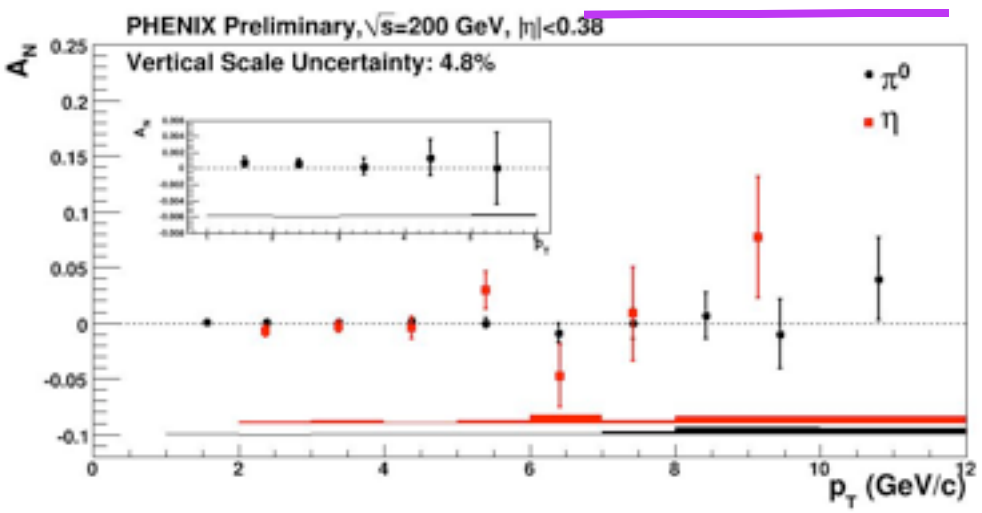
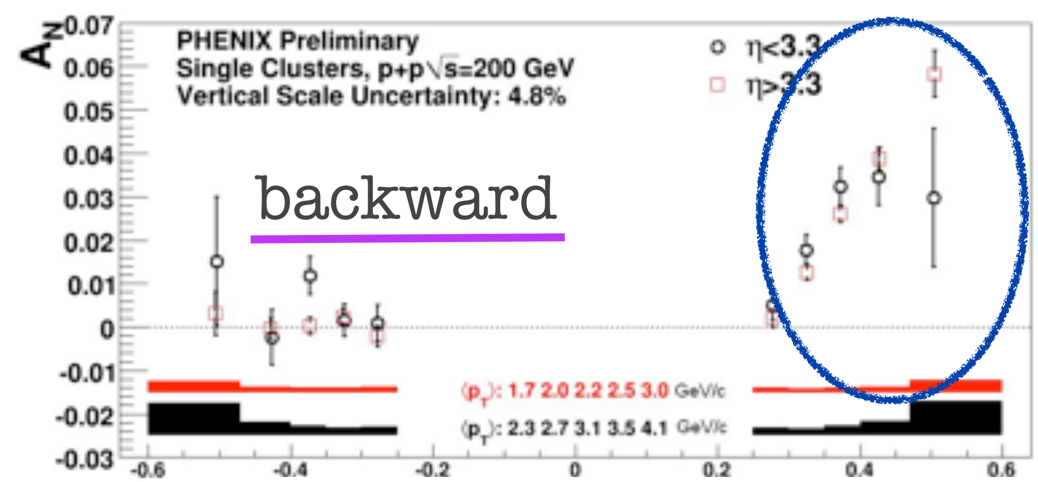
Transverse Single Spin Asymmetries

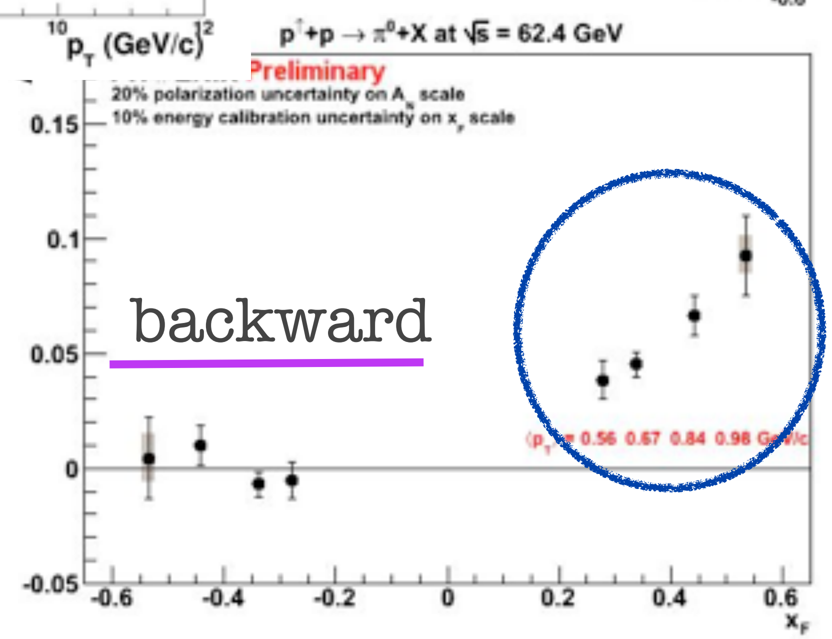


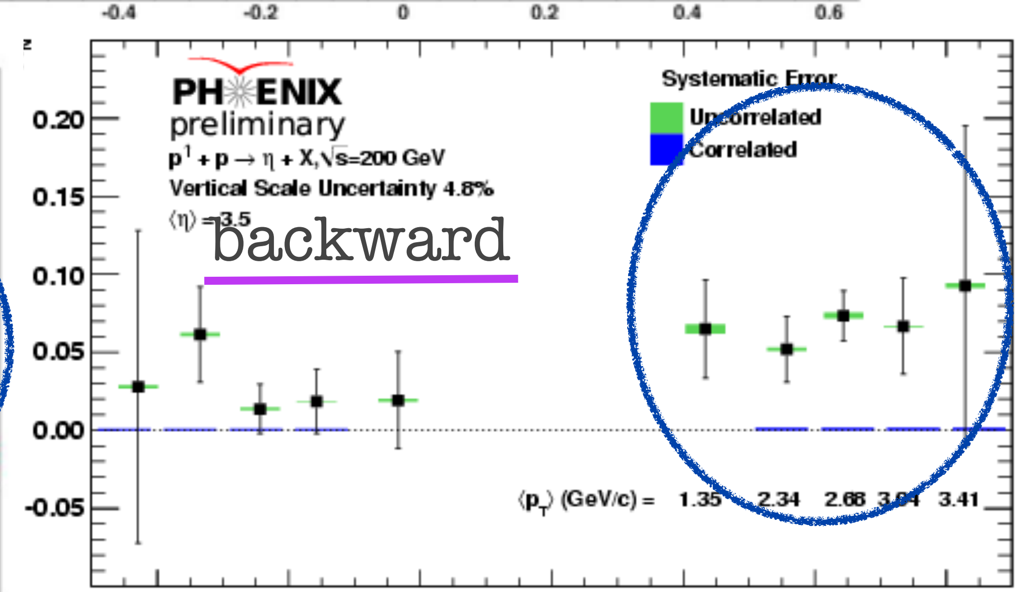




Zero asymmetry in the midrapidity and backward regions

Large asymmetry in the forward region !!





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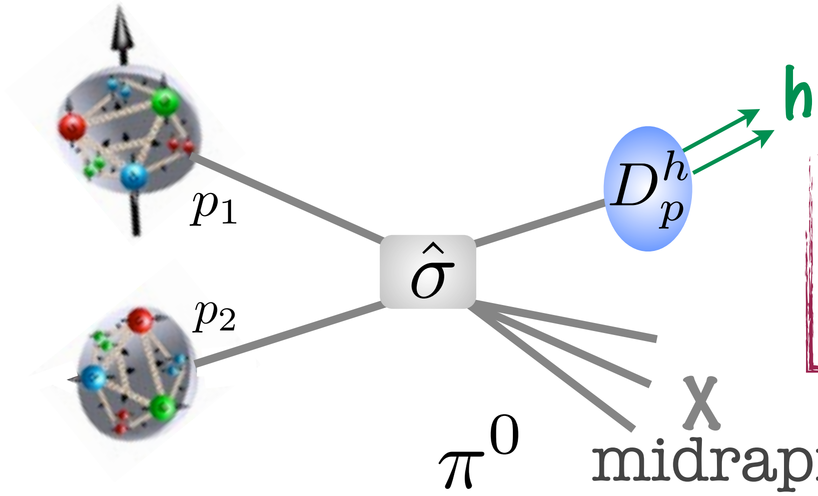
Transverse Single Spin Asymmetries



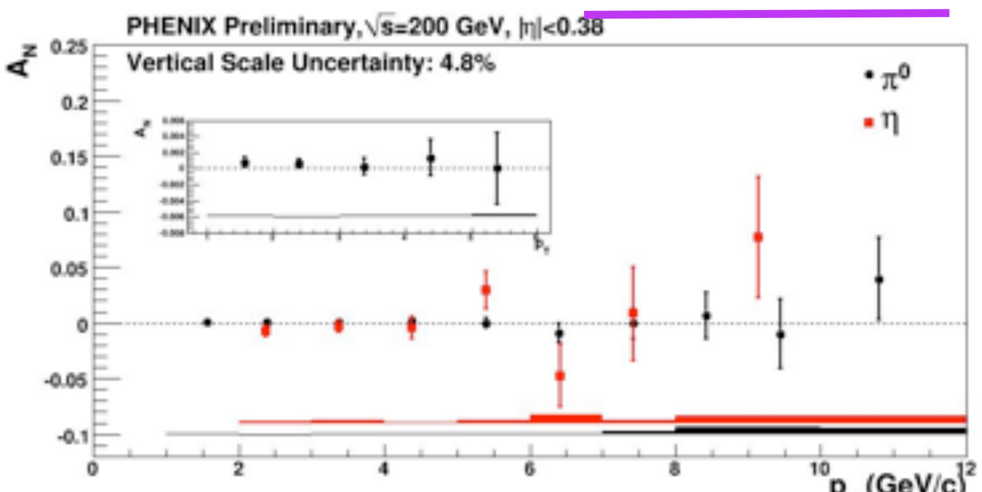
midrapidities

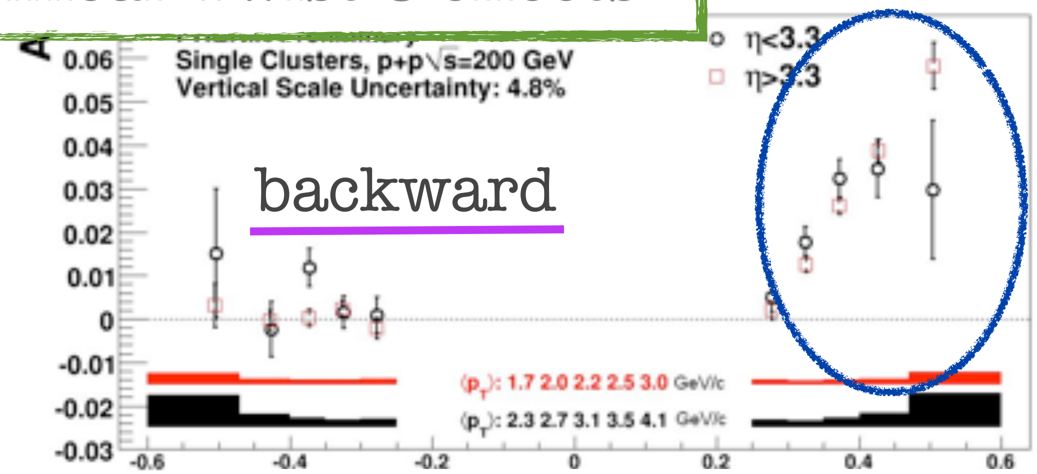
What generates these large asymmetries?

Initial State Interaction
SIVERS effect

Final State Interaction
TRANSVERSITY x COLLINS

Collinear Twist-3 effects





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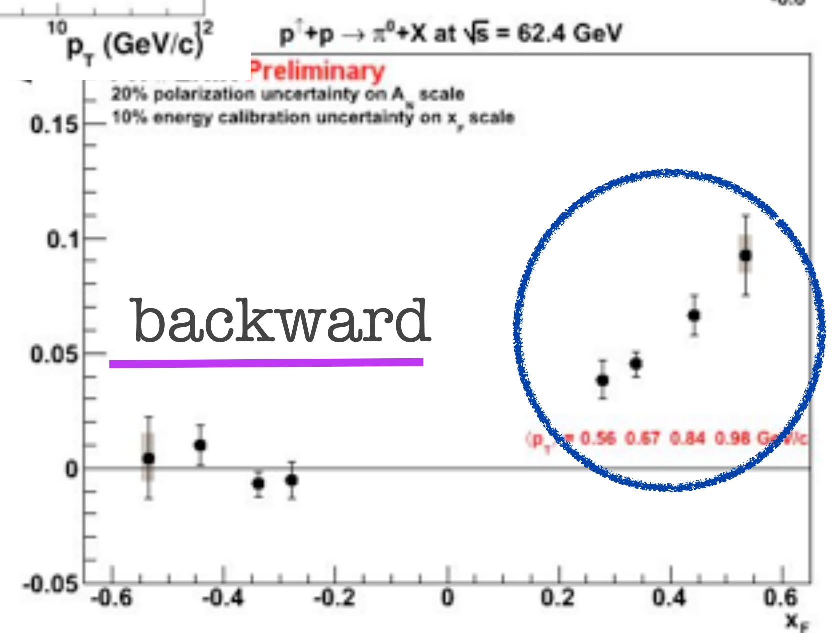

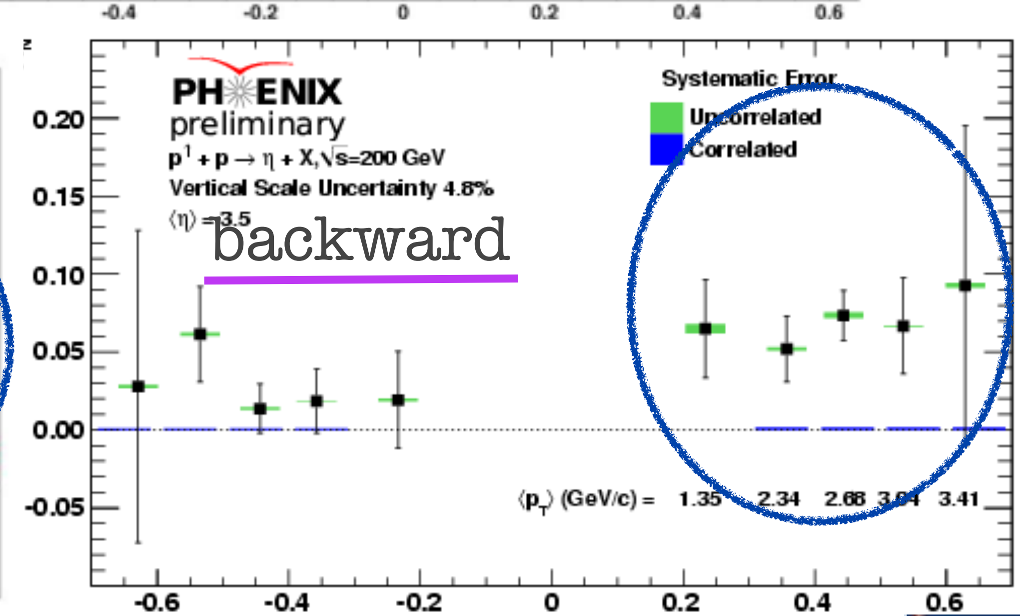

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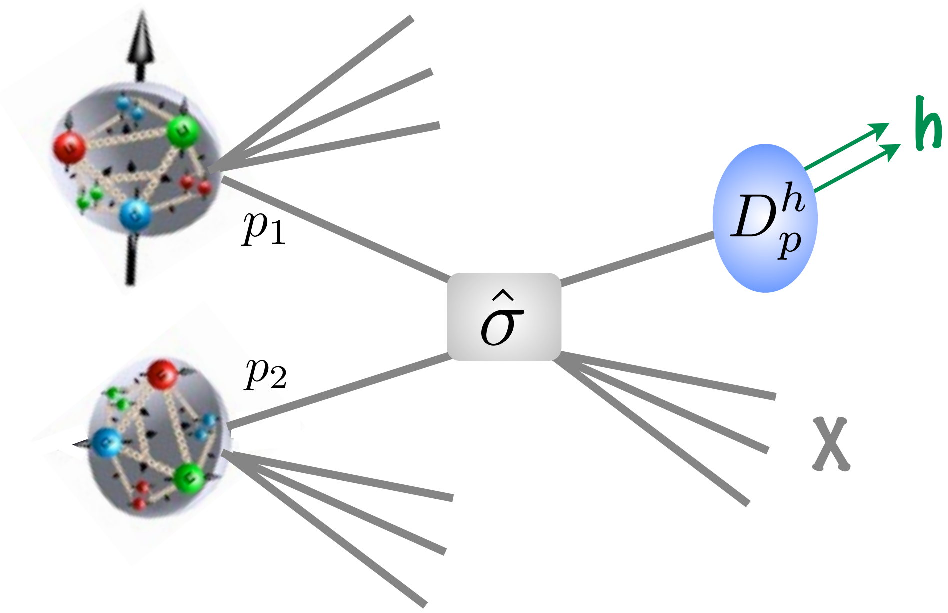
Sivers mechanism

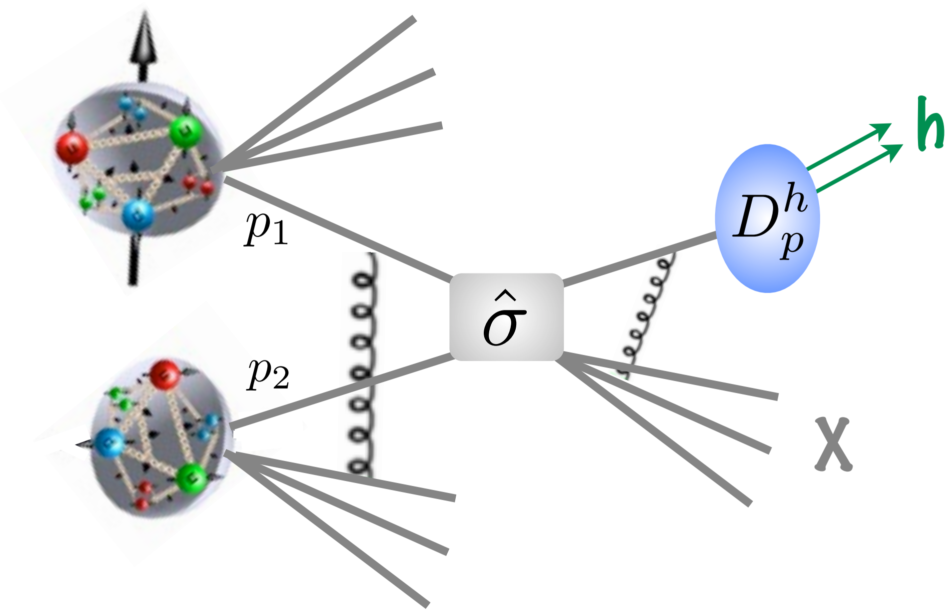


Sivers mechanism:

Azimuthal asymmetry generated by correlations between quark transverse momentum and the proton transverse spin

		quark		
		U	L	T
nucleon	U	f_1		$h_1^\perp$
	L		g_1	$h_{1L}^\perp$
	T	$\boxed{f_{1T}^\perp}$	$g_{1T}^\perp$	h_1, $h_{1T}^\perp$

Sivers mechanism



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naive T-odd function

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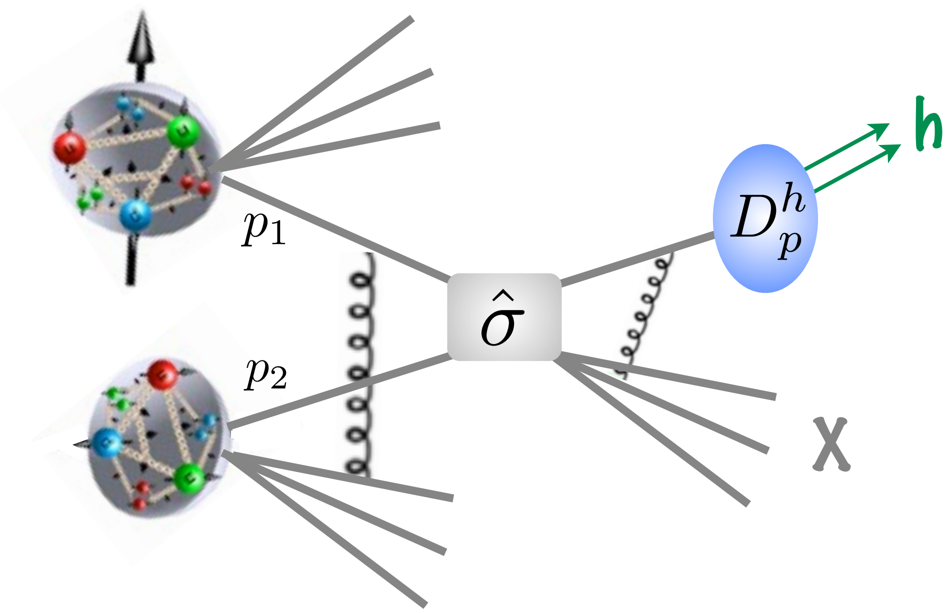

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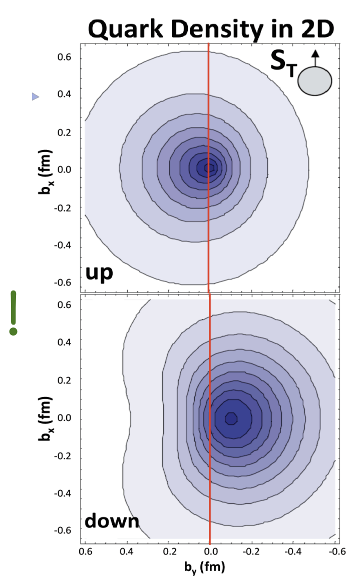
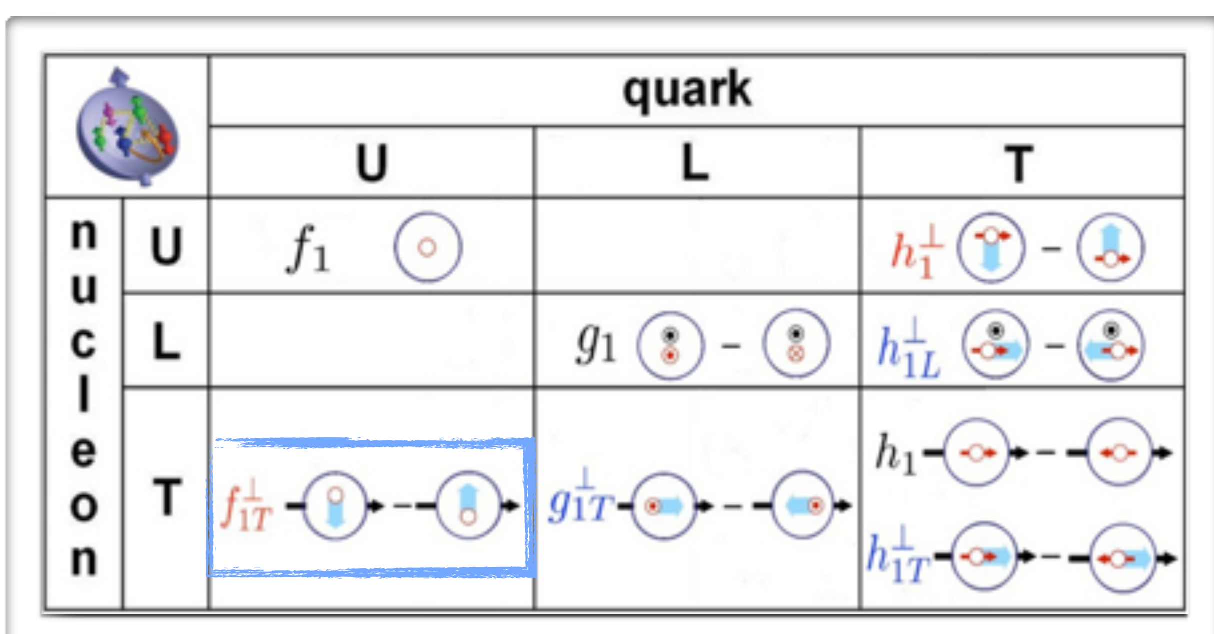
Spatial deformation due to spin-orbit correlations:
=> non zero Orbital Angular Momentum!



Lattice QCD PRL98:222001,2007.



nucleon \ quark	U	L	T
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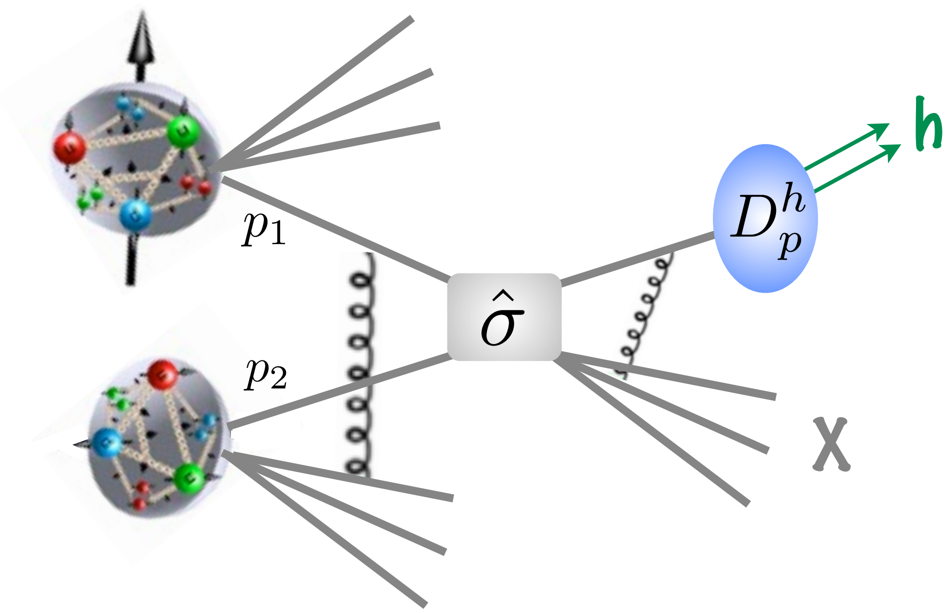

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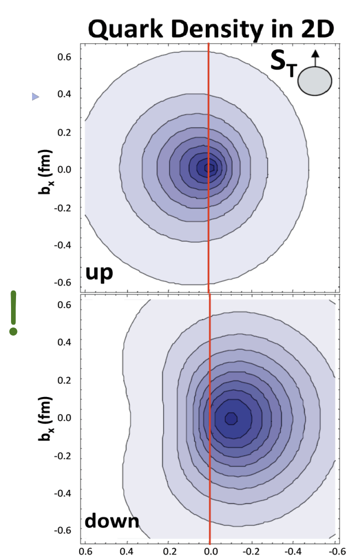

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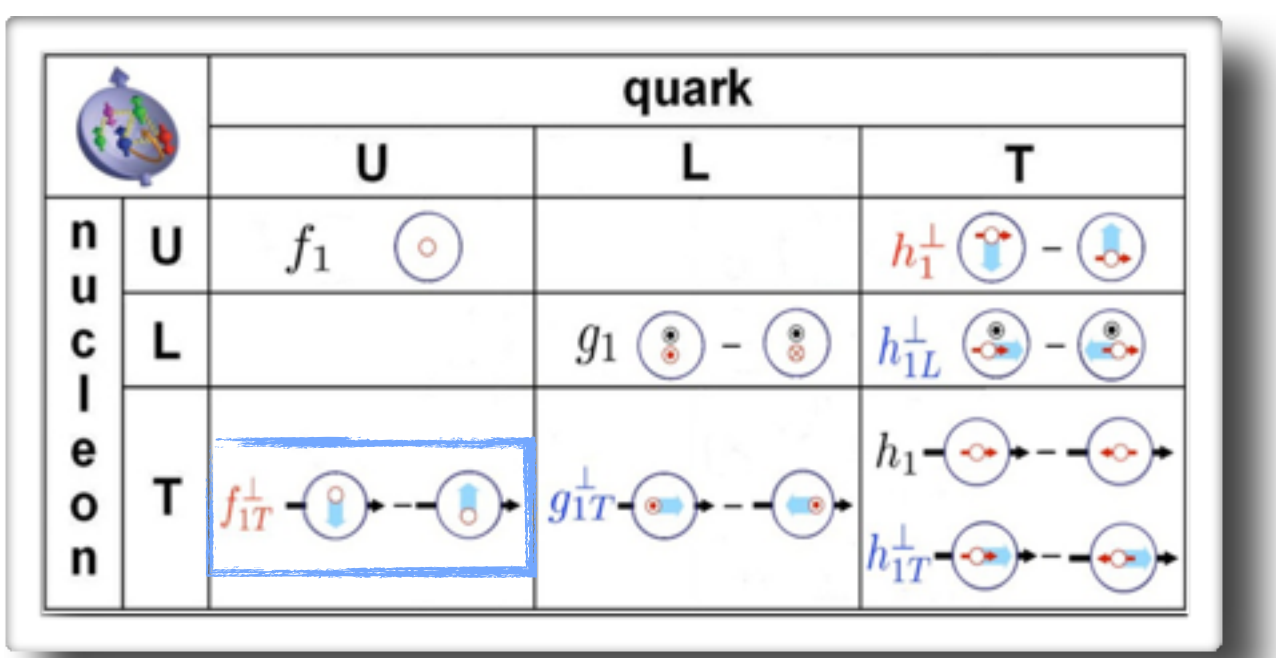

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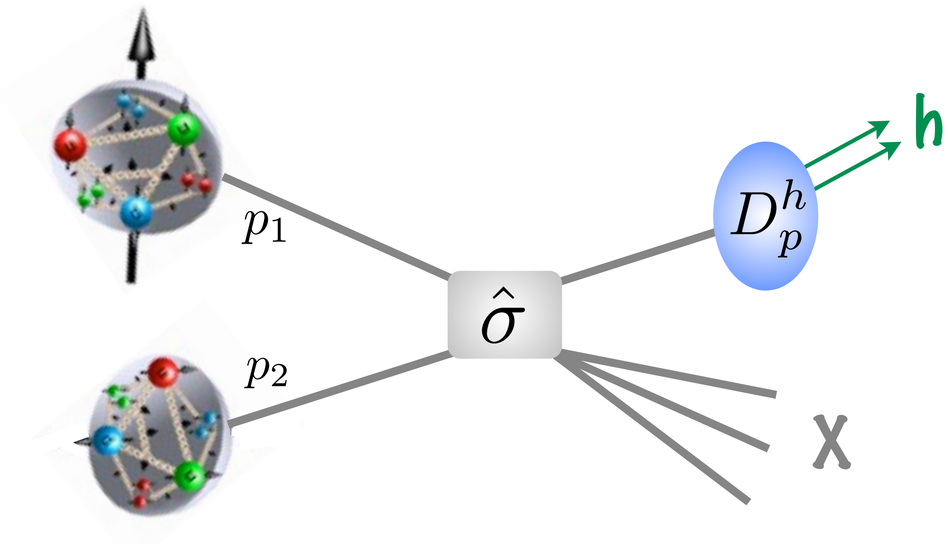
BUT!!

TMD factorization not valid in pp => hadron reaction!

Transversity via Collins



$$A_N \propto h_1 \times H_1^\perp$$

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		U	L	T
nucleon	U	f_1		$h_1^\perp$
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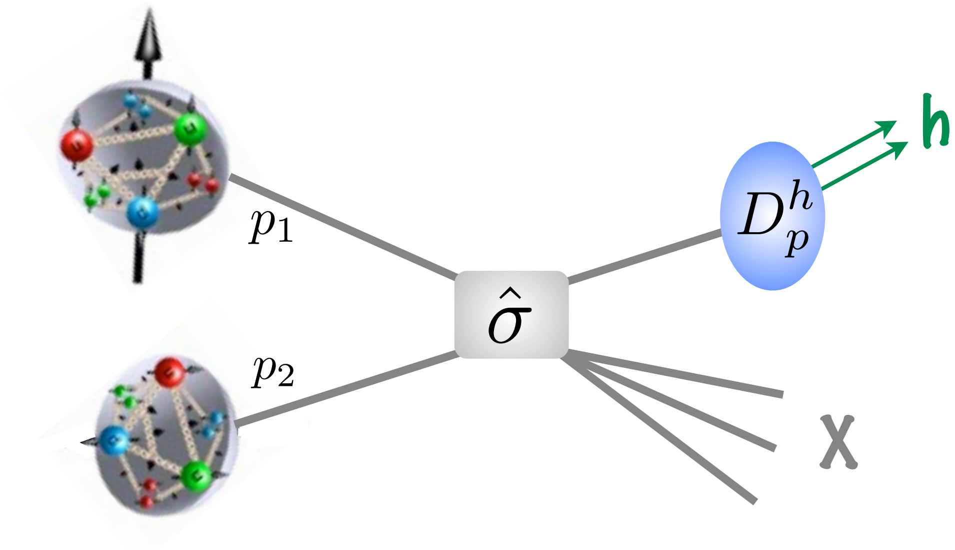

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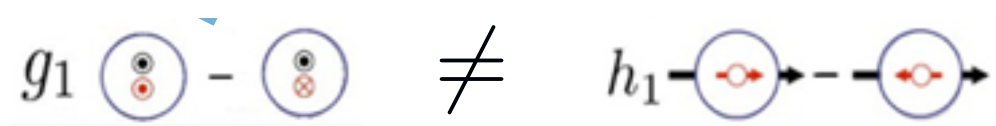

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		U	L	T
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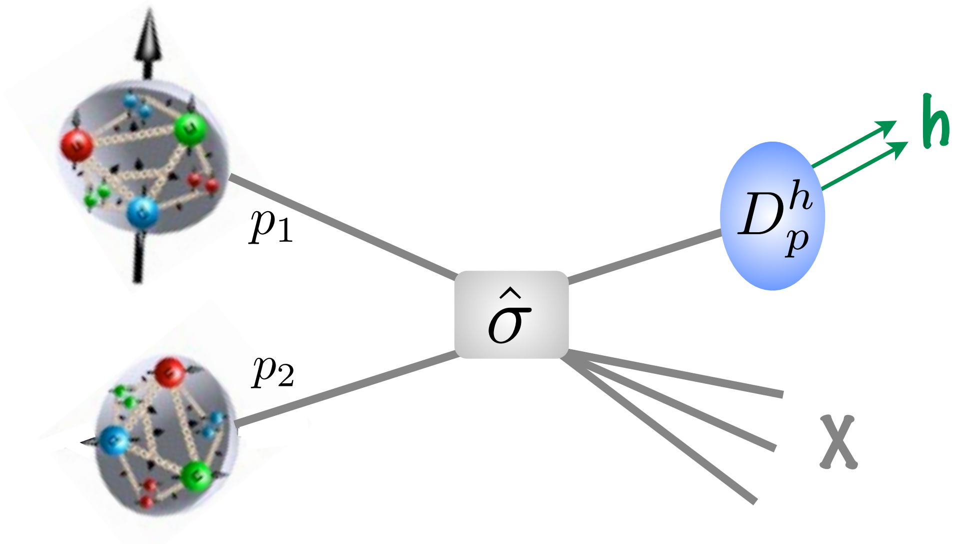

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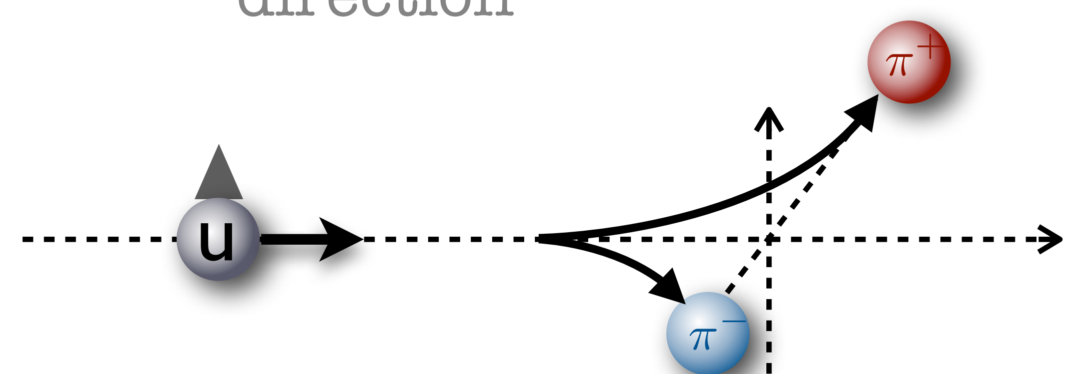
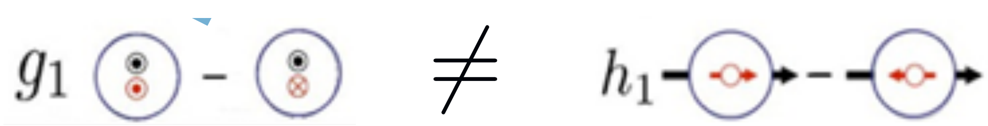
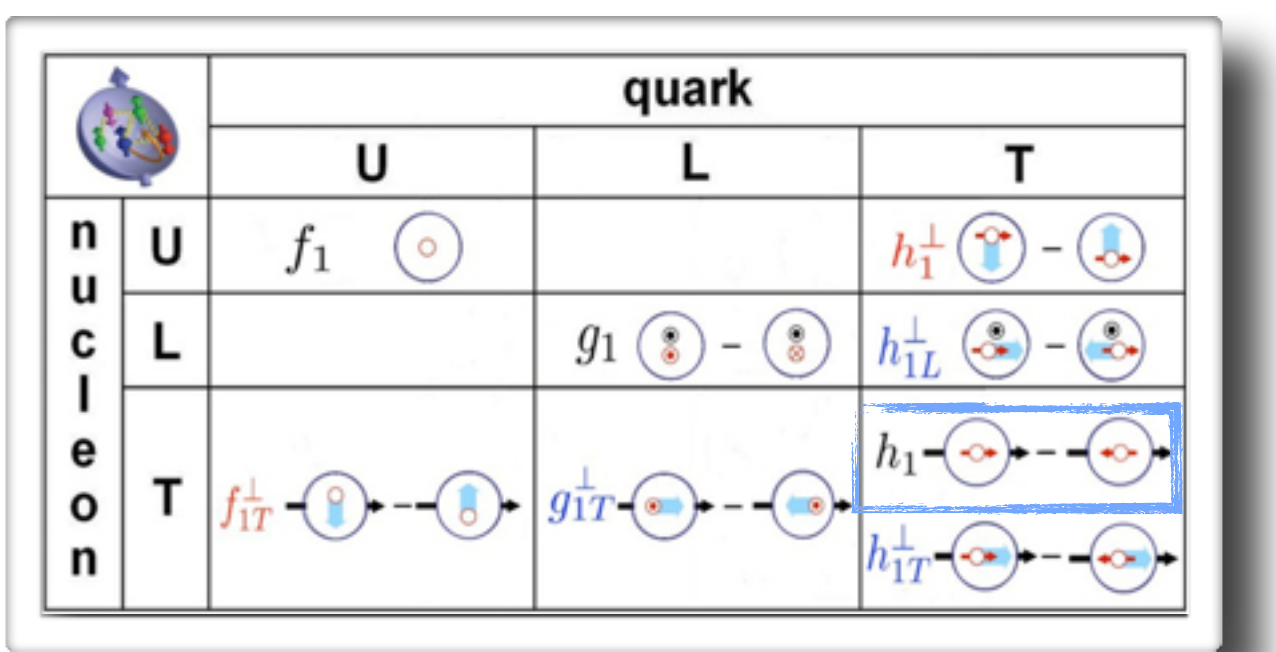
Collins mechanism:

left-right asymmetry from correlations between quark transverse spin and outgoing hadron direction







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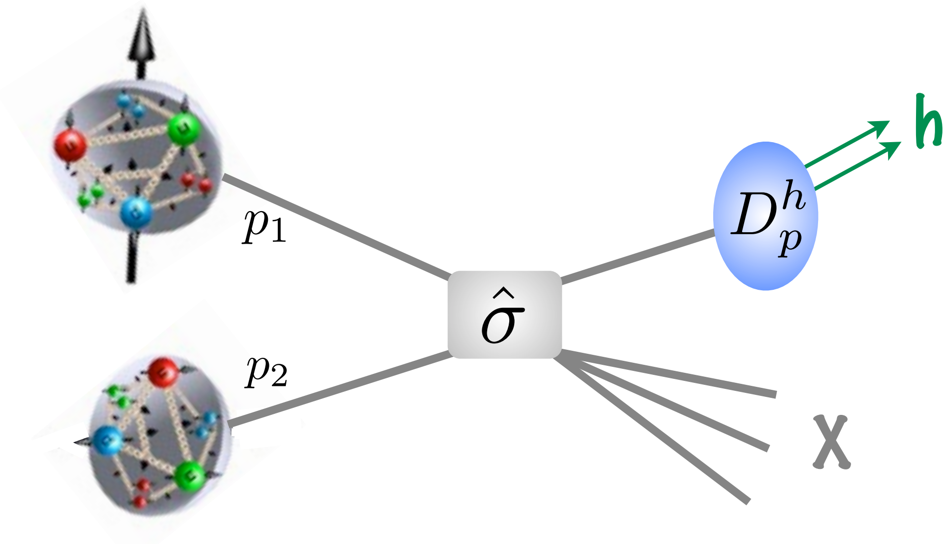

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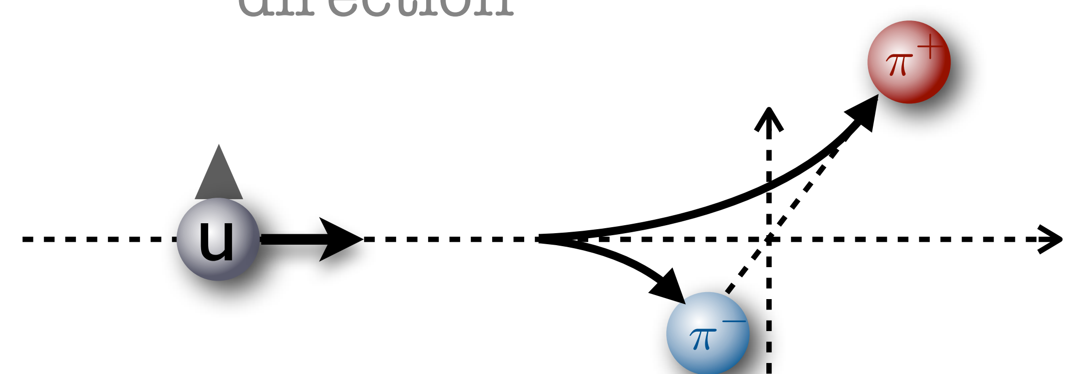

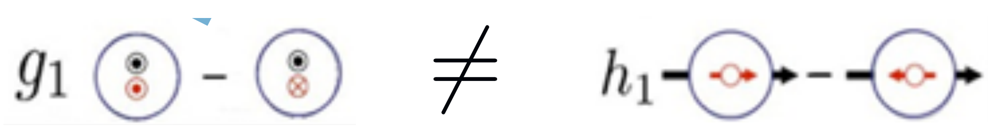

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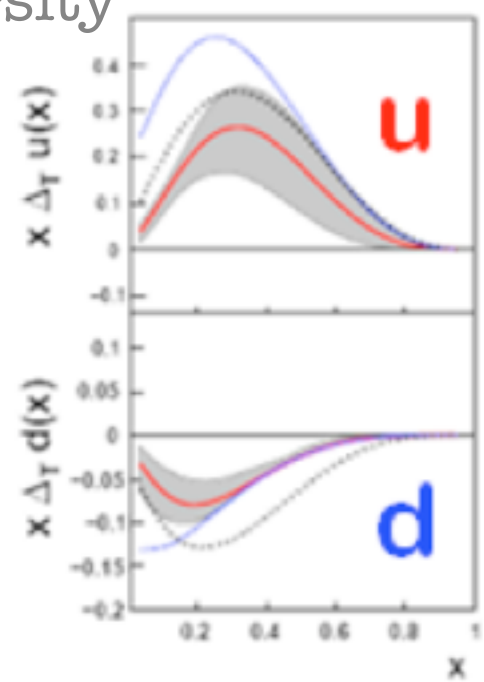
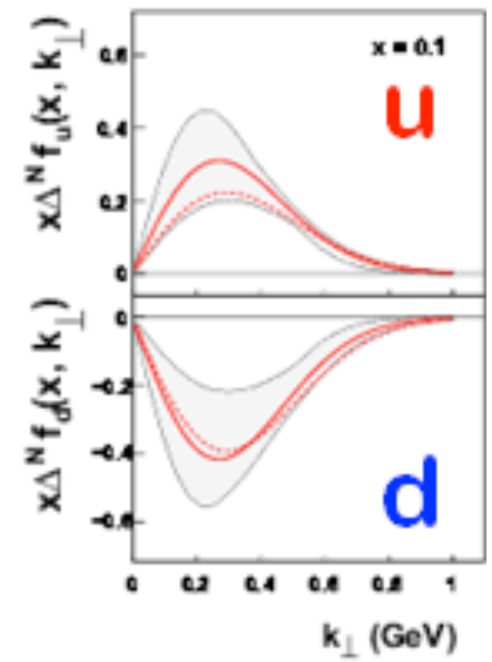
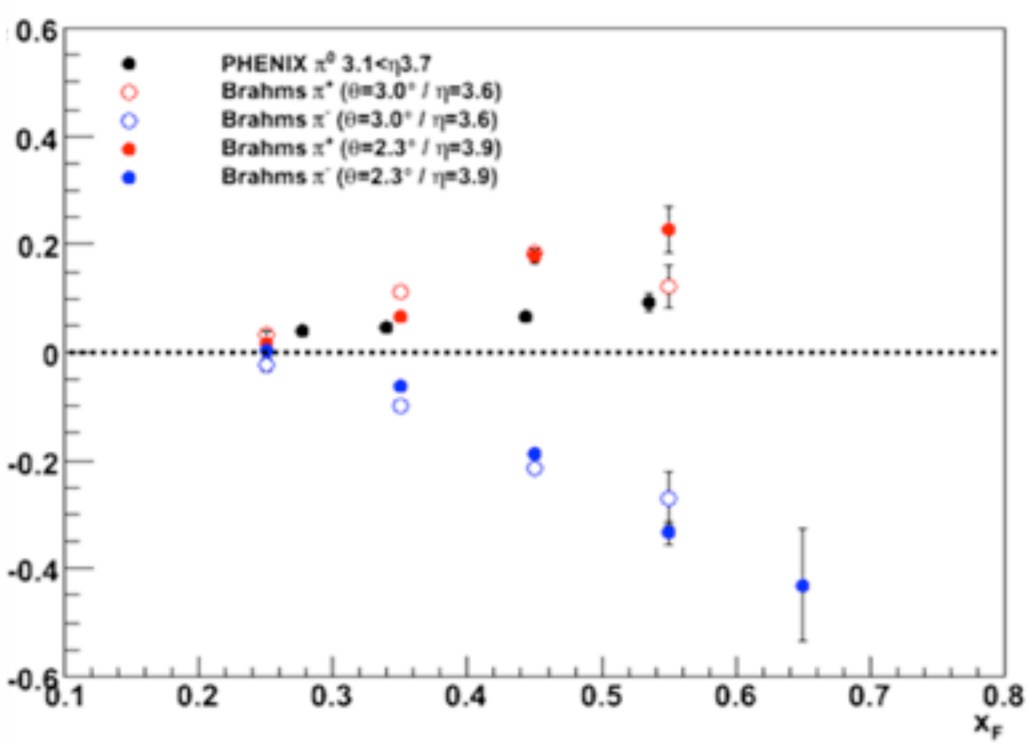
Which effect?

Transversity



Sivers





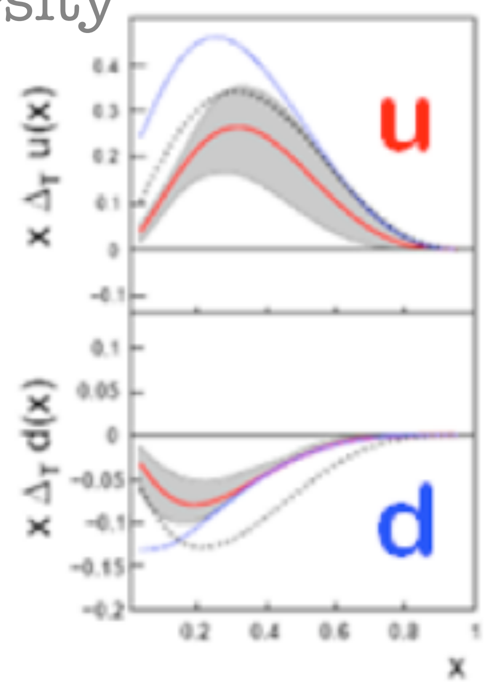
$$\pi^+ \, (u\bar{d})$$

$$\pi^0 \, (u\bar{u} + d\bar{d})$$

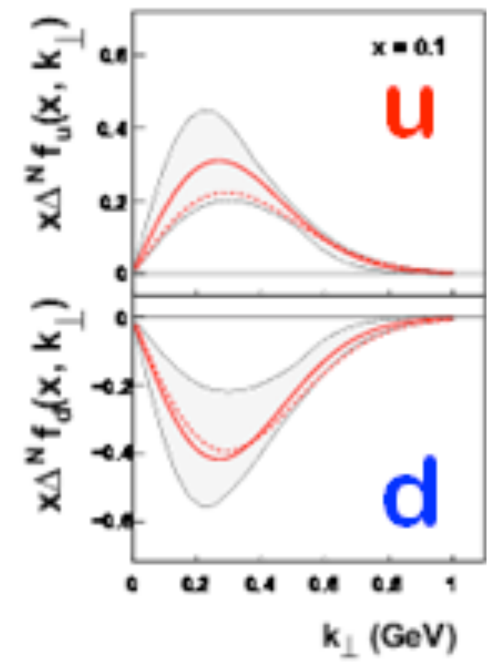
$$\pi^- \, (\bar{u}d)$$

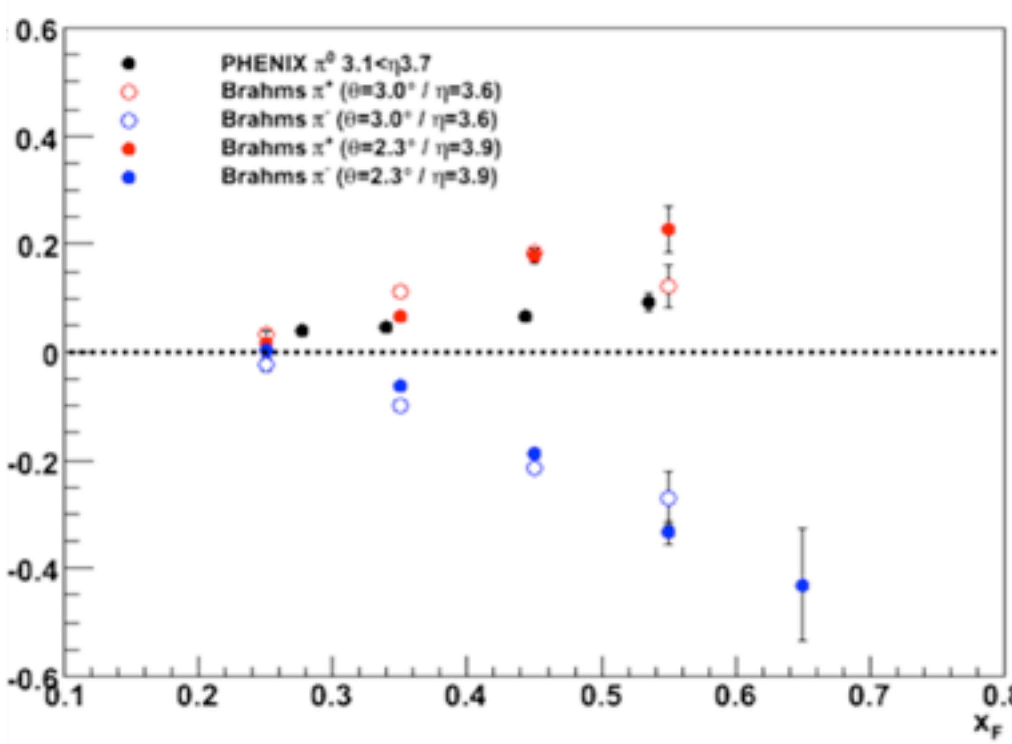
Which effect?

Transversity



Sivers





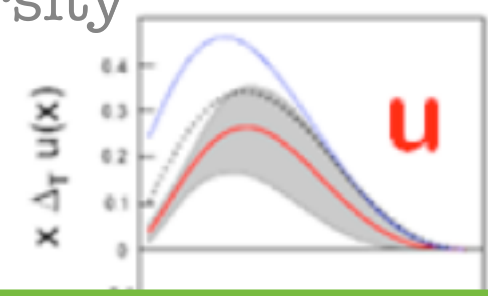
$\pi^+ \, (u\bar{d}) \qquad u : d \rightarrow \pi^+ \qquad 1:0$

$\pi^0 \, (u\bar{u} + d\bar{d}) \qquad u : d \rightarrow \pi^0 \qquad 2:1$

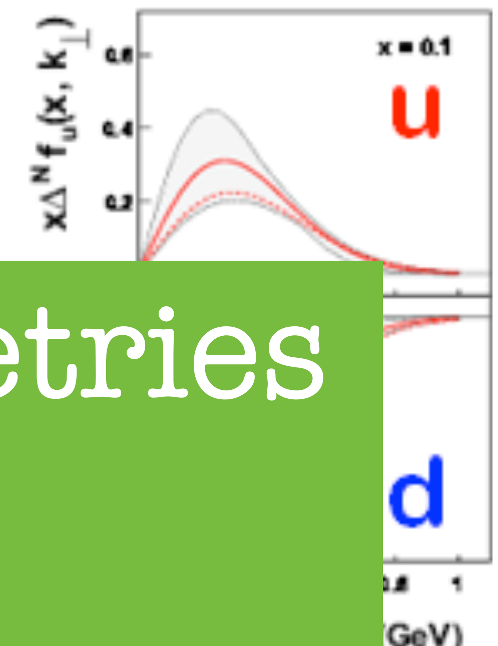
$\pi^- \, (\bar{u}d) \qquad u : d \rightarrow \pi^- \qquad 1:1$

Which effect?

Transversity



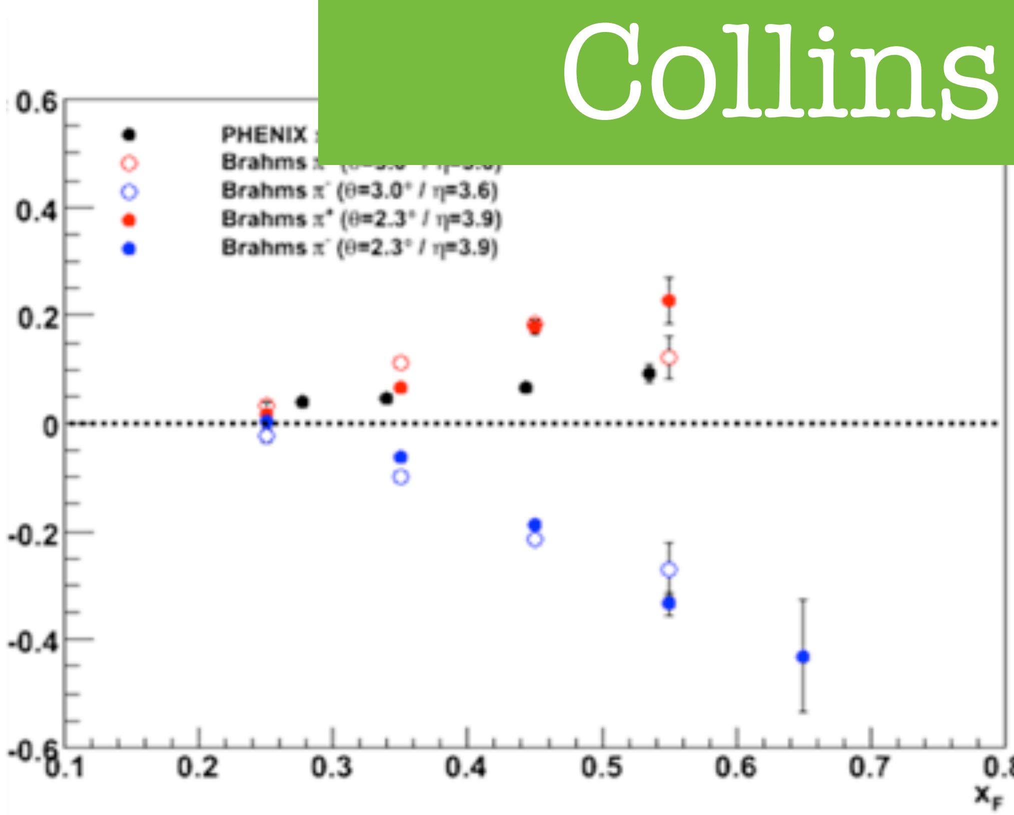
Sivers



Single Spin Asymmetries

=

Collins + Sivers + ...



$1:0$

$\pi^0\,(u\bar{u}+d\bar{d})\quad u:d\to\pi^0\quad 2:1$

$\pi^-\,(\bar{u}d)\quad u:d\to\pi^-\quad 1:1$

How to separate the contributions?

Initial State Interaction
SIVERS effect

Final State Interaction
TRANSVERSITY x COLLINS

How to separate the contributions?

- Transversity via IFF
- Sivers in Drell-Yan
- Jet asymmetries (Sivers)
- Asymmetries within a jet (Collins)

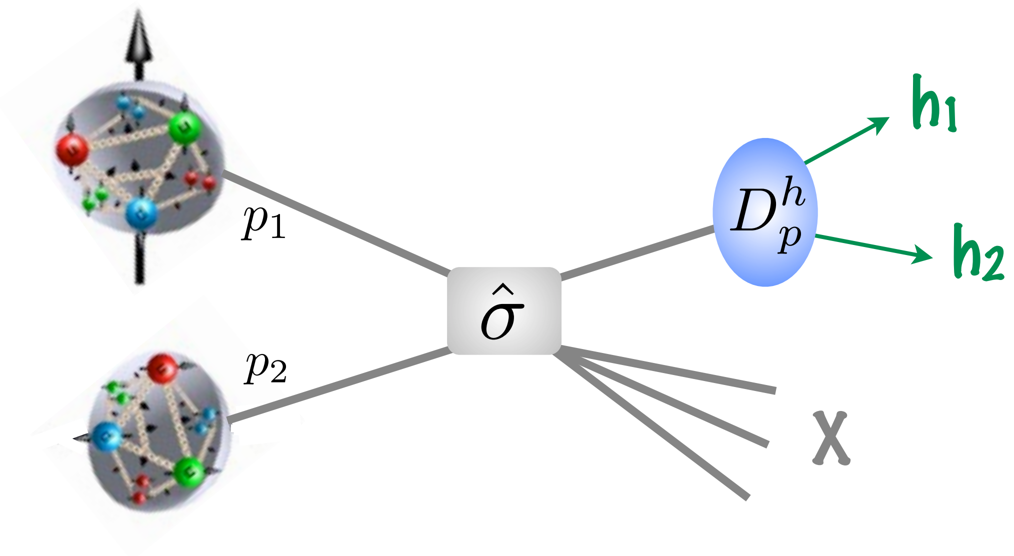
Initial State Interaction
SIVERS effect

Final State Interaction
TRANSVERSITY x COLLINS

Transversity x IFF

Interference Fragmentation:

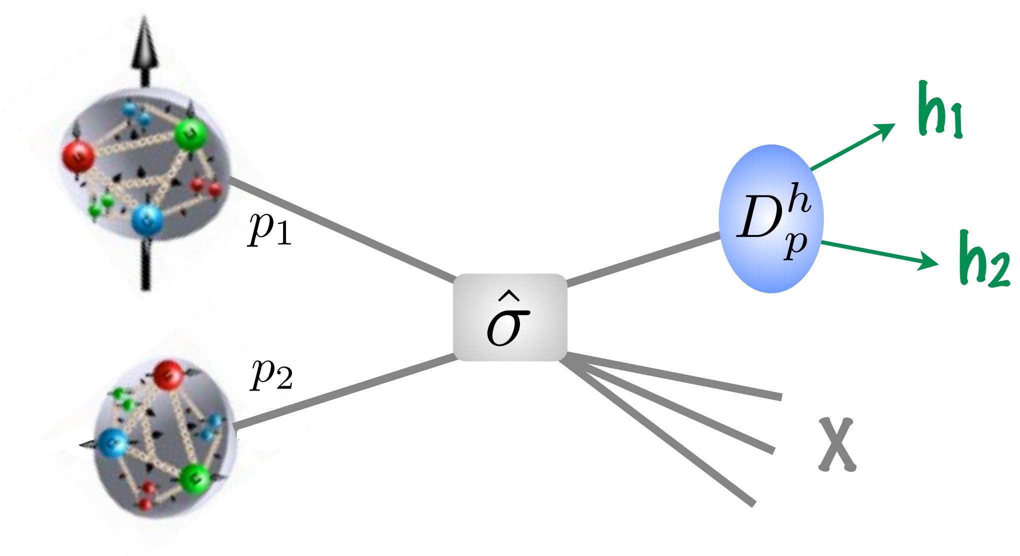
left-right asymmetry from correlations between quark transverse spin and relative orbital angular momentum of the hadron pair

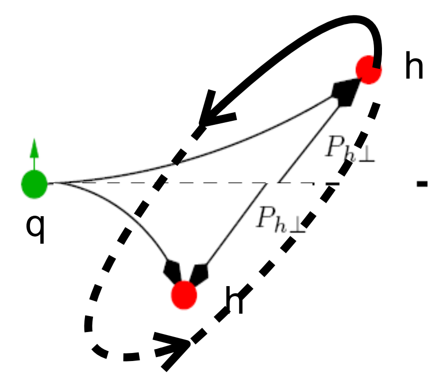


Transversity x IFF

<u>Interference Fragmentation:</u>

left-right asymmetry from correlations between quark transverse spin and relative orbital angular momentum of the hadron pair

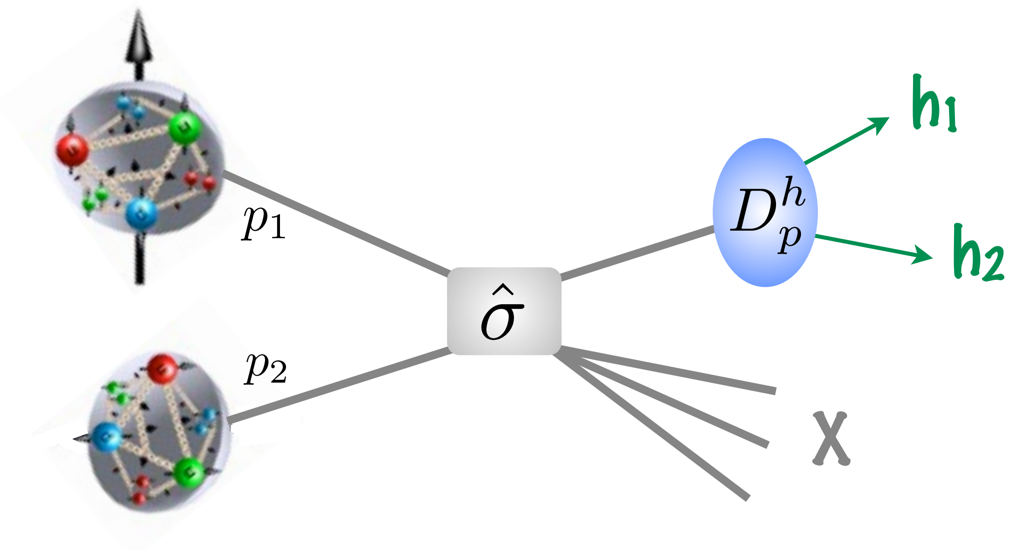


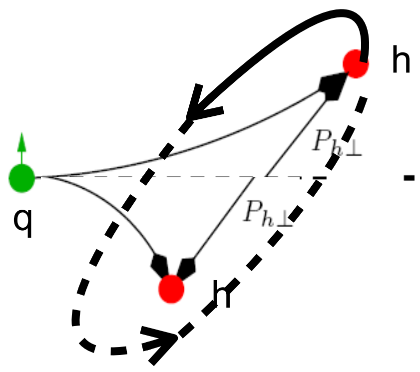


Collinear, no TMD!

Transversity x IFF

<u>Interference Fragmentation:</u>
left-right asymmetry from correlations between quark transverse spin and relative orbital angular momentum of the hadron pair



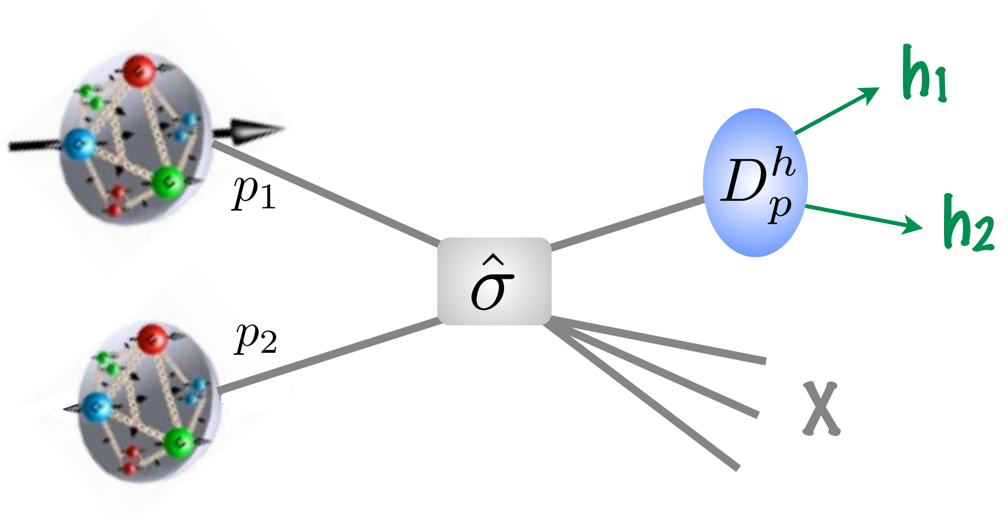


Collinear, no TMD!

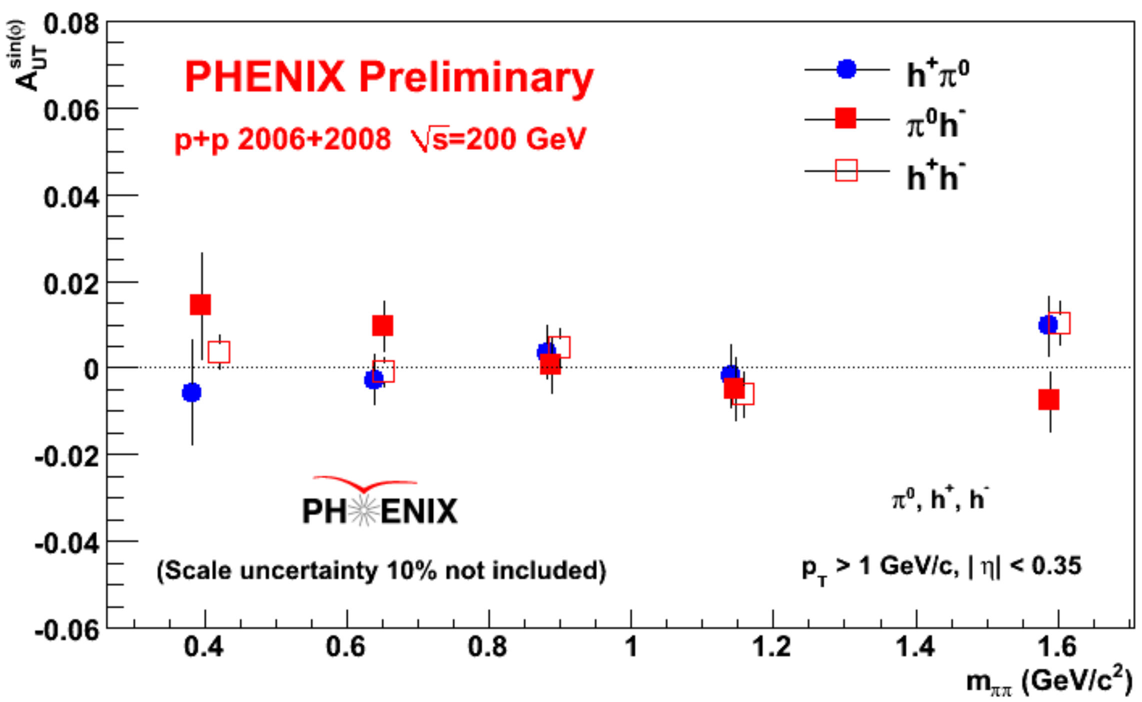
Collinear factorization

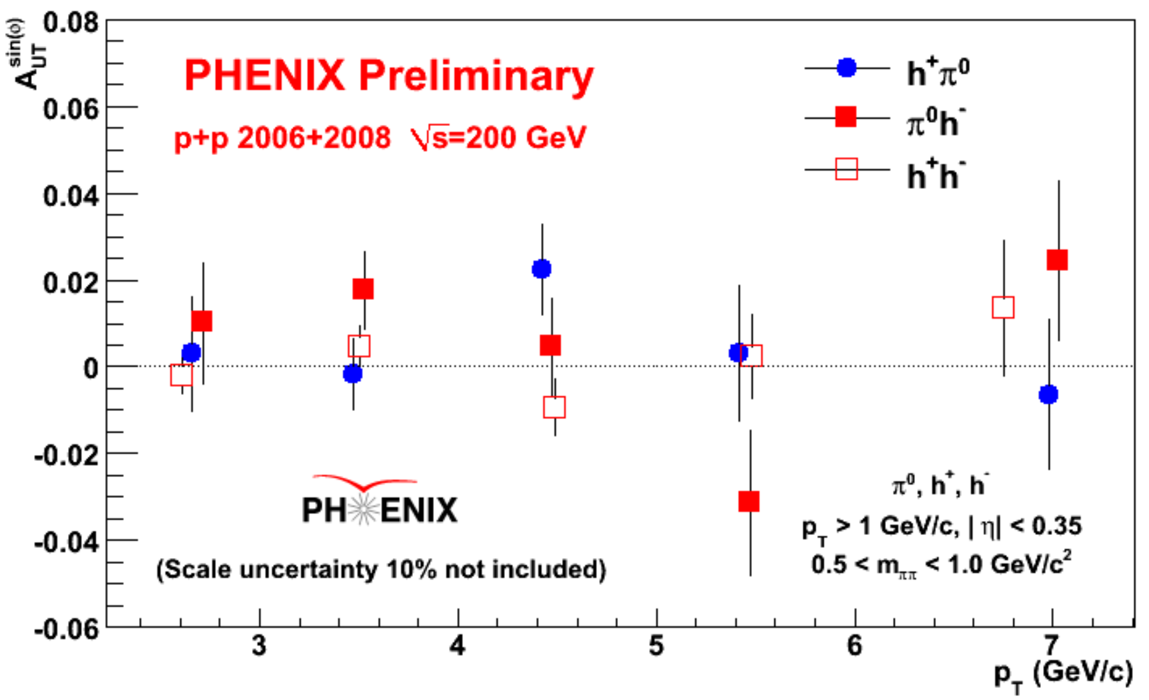
Independent access to transversity → Measure of TMD factorization breaking in pp => hadrons reaction

Transversity x IFF @ midrapidity

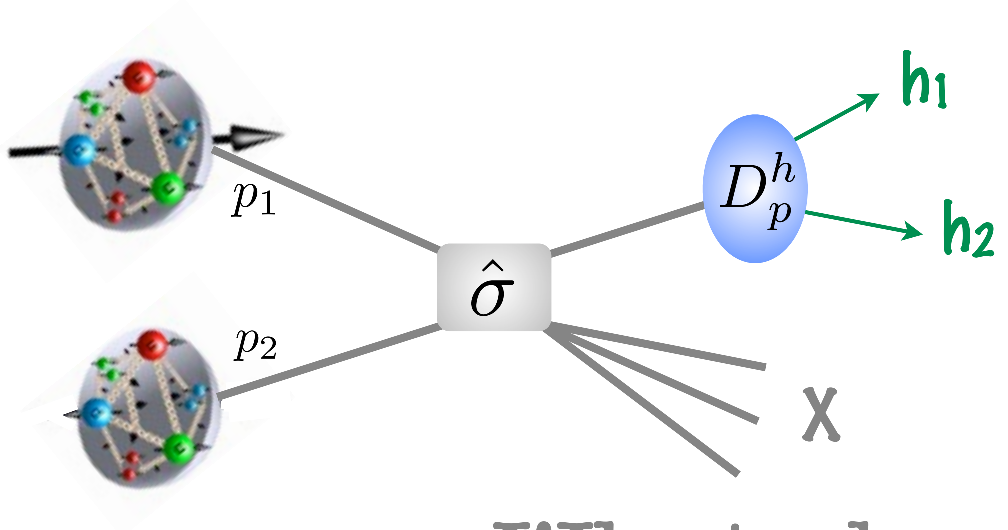


$$A_N \propto h_1 \times H_1^{\angle}$$



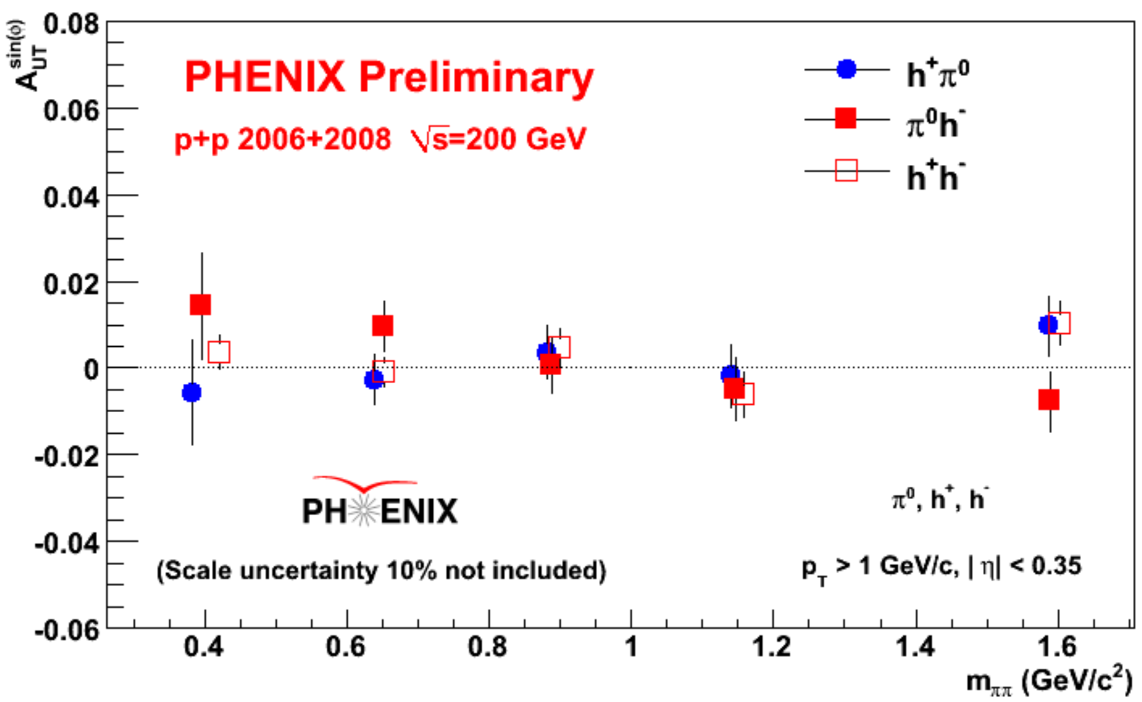


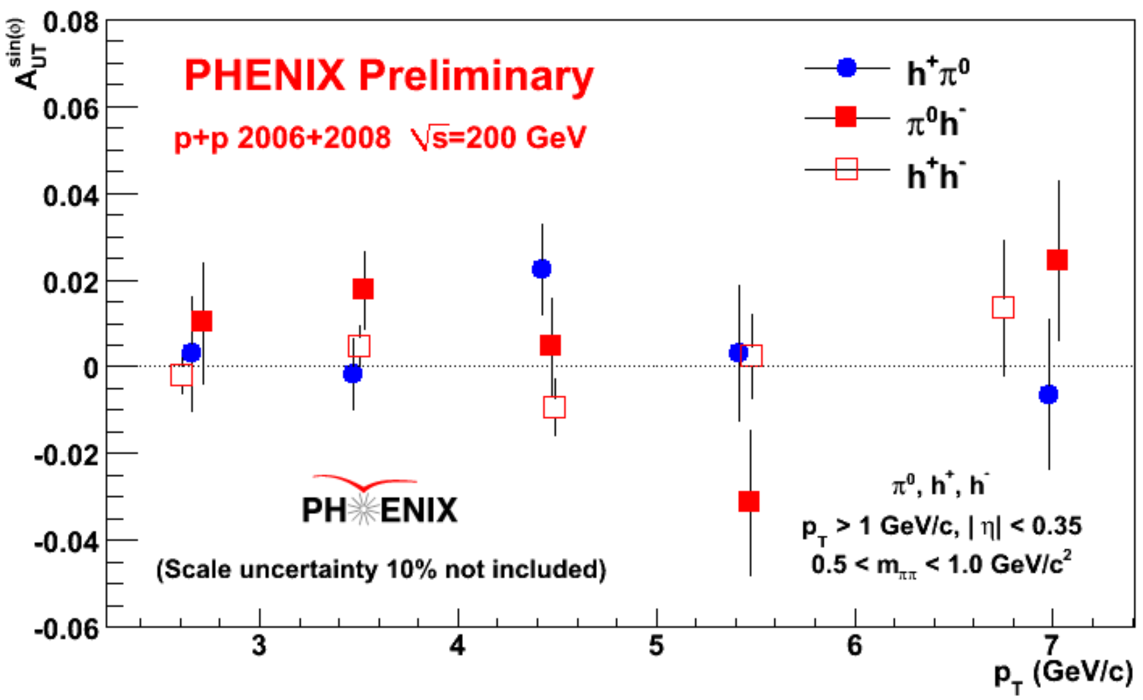
Transversity x IFF @ midrapidity



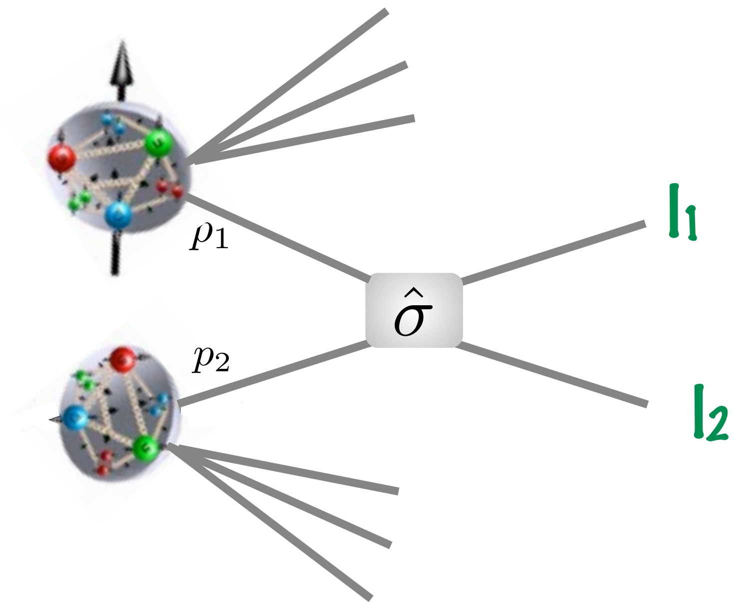
$$A_N \propto h_1 \times H_1^{\angle}$$

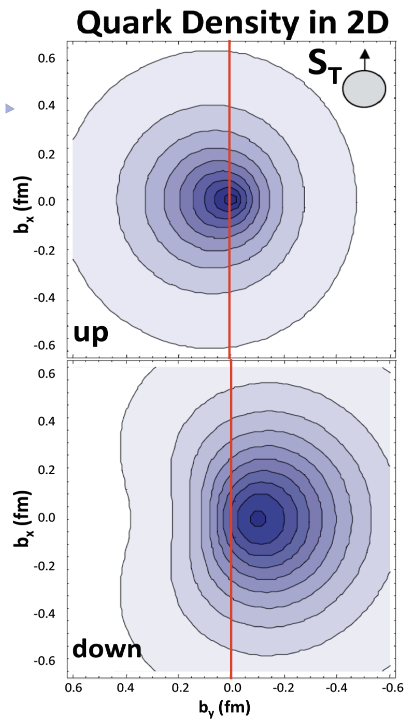
What about Forward rapidities?





Sivers in Drell-Yan

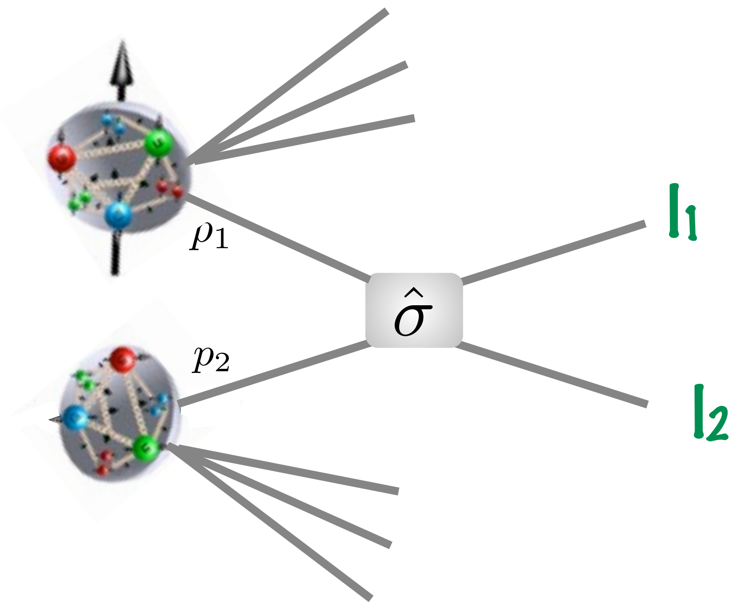




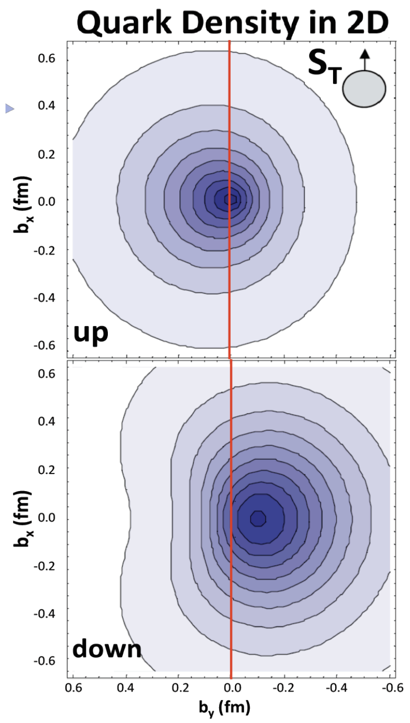
Lattice QCD PRL98:222001,2007.

Sivers effect gives access to the spatial quark distribution, and, indirectly, on OAM

Sivers in Drell-Yan



- TMD Factorization apply



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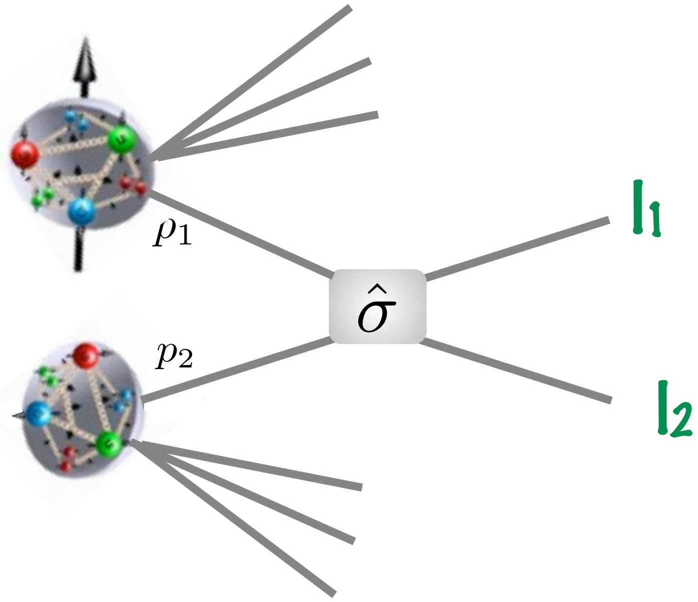
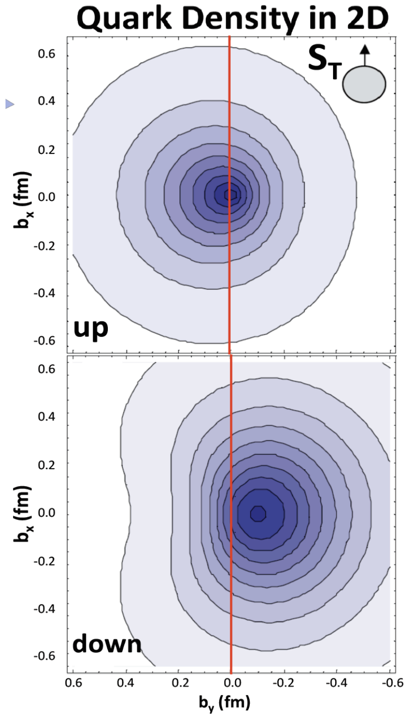


- TMD Factorization apply
- No fragmentation



Lattice QCD PRL98:222001,2007.

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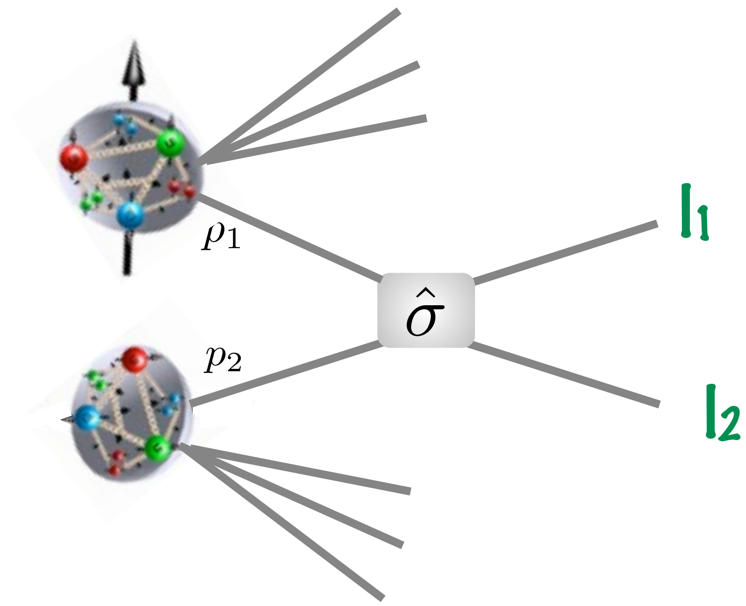
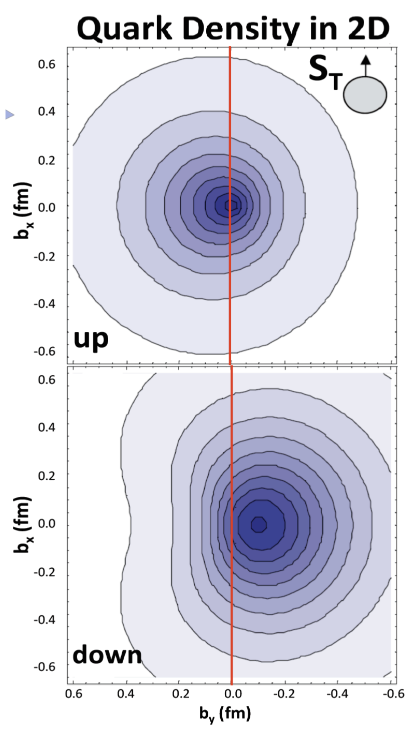
Sivers in Drell-Yan



- TMD Factorization apply
- No fragmentation
- Important TMD framework test

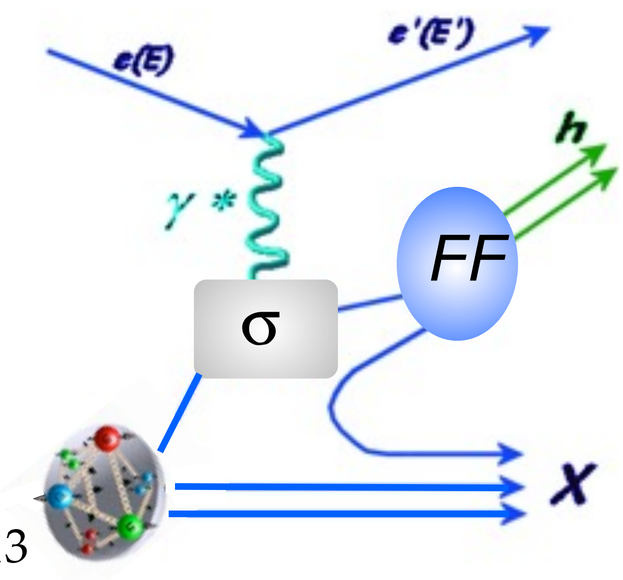
$$\mathrm{TSSA}^{\mathrm{DY}}_{\mathrm{SIVERS}} = -\ \mathrm{TSSA}^{\mathrm{SIDIS}}_{\mathrm{SIVERS}}$$

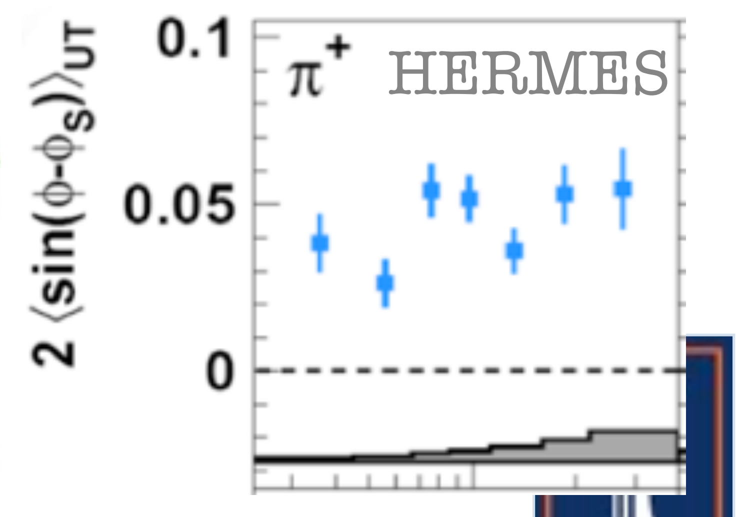


Lattice QCD PRL98:222001,2007.

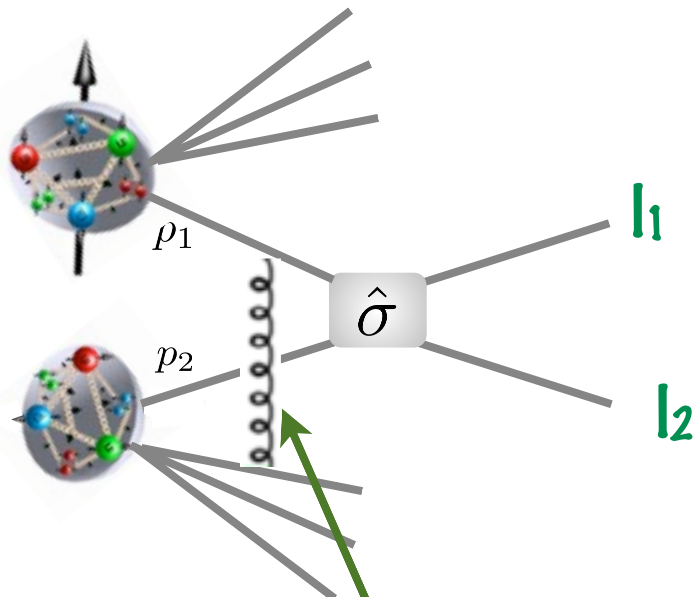
Sivers effect gives access to the spatial quark distribution, and, indirectly, on OAM

SIDIS





Sivers in Drell-Yan



- TMD Factorization apply
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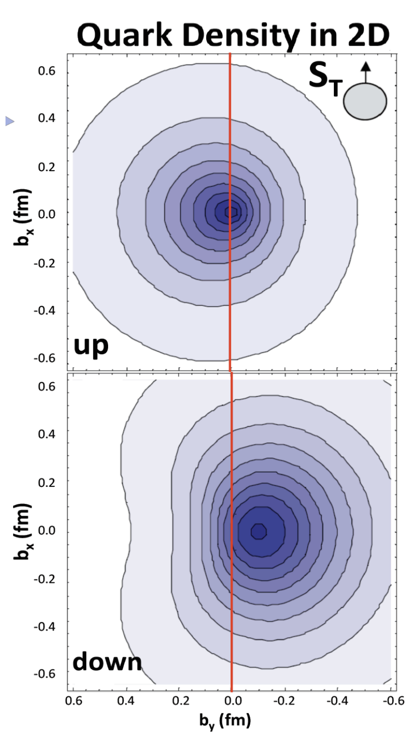
- Important TMD framework test

$$\mathrm{TSSA}^{\mathrm{DY}}_{\mathrm{SIVERS}} = -\,\mathrm{TSSA}^{\mathrm{SIDIS}}_{\mathrm{SIVERS}}$$

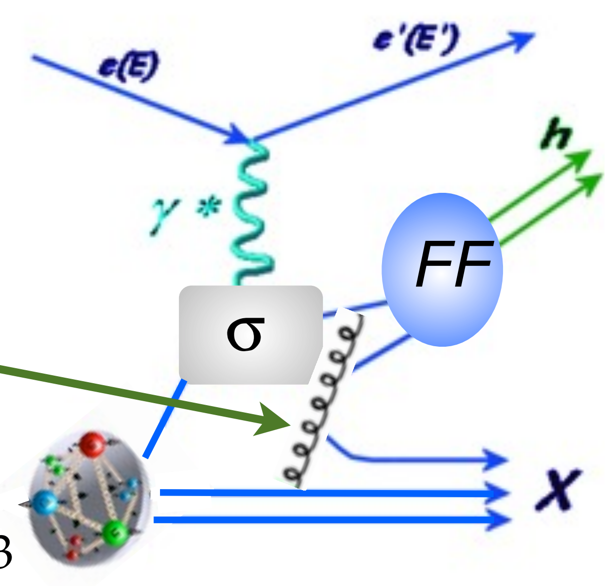


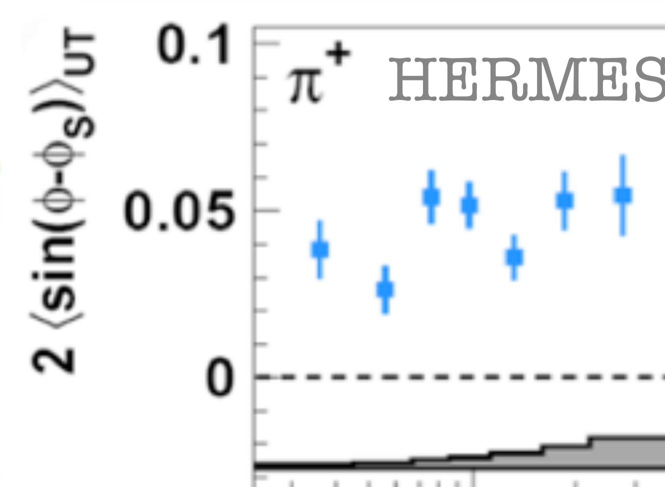
Lattice QCD PRL98:222001,2007.

Sivers effect gives access to the spatial quark distribution, and, indirectly, on OAM

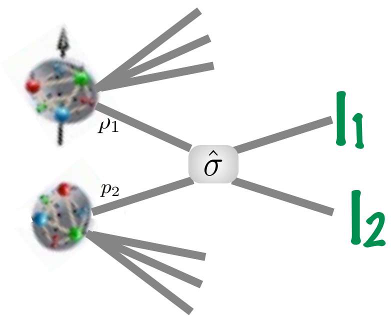
naive T-odd function

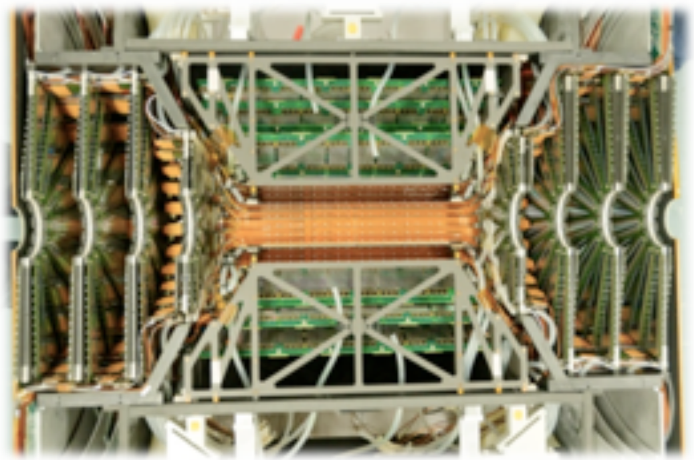
SIDIS



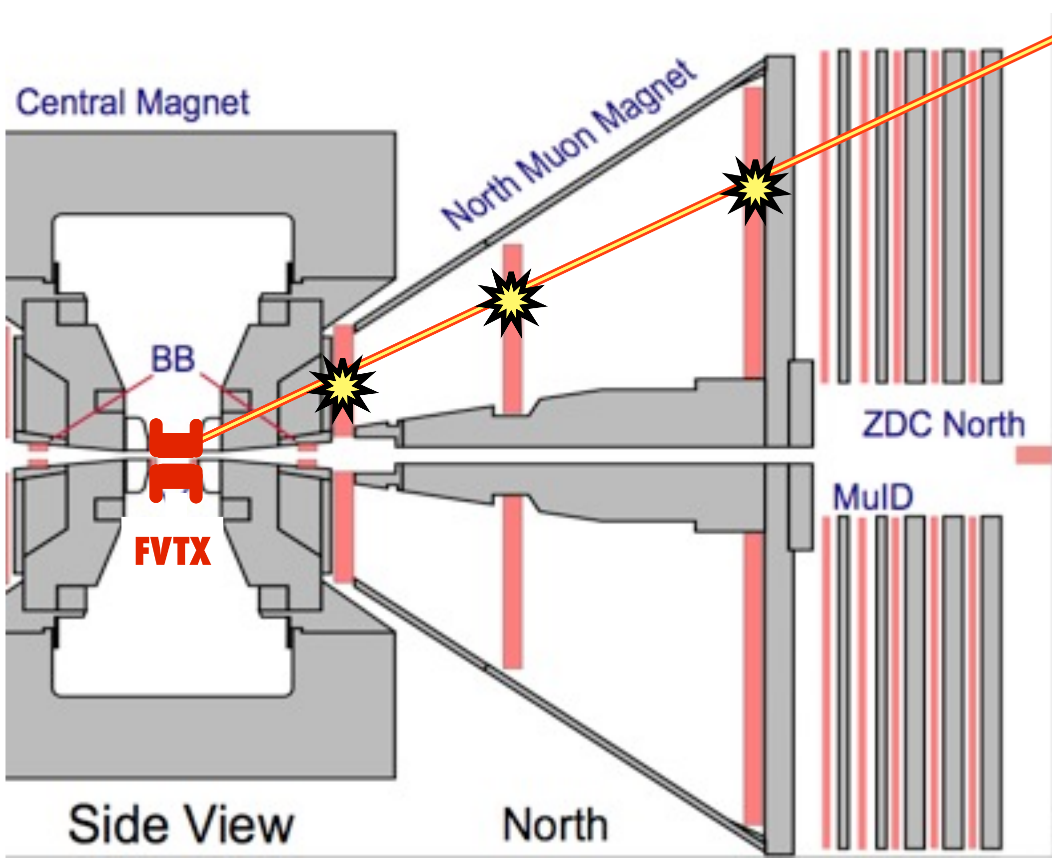


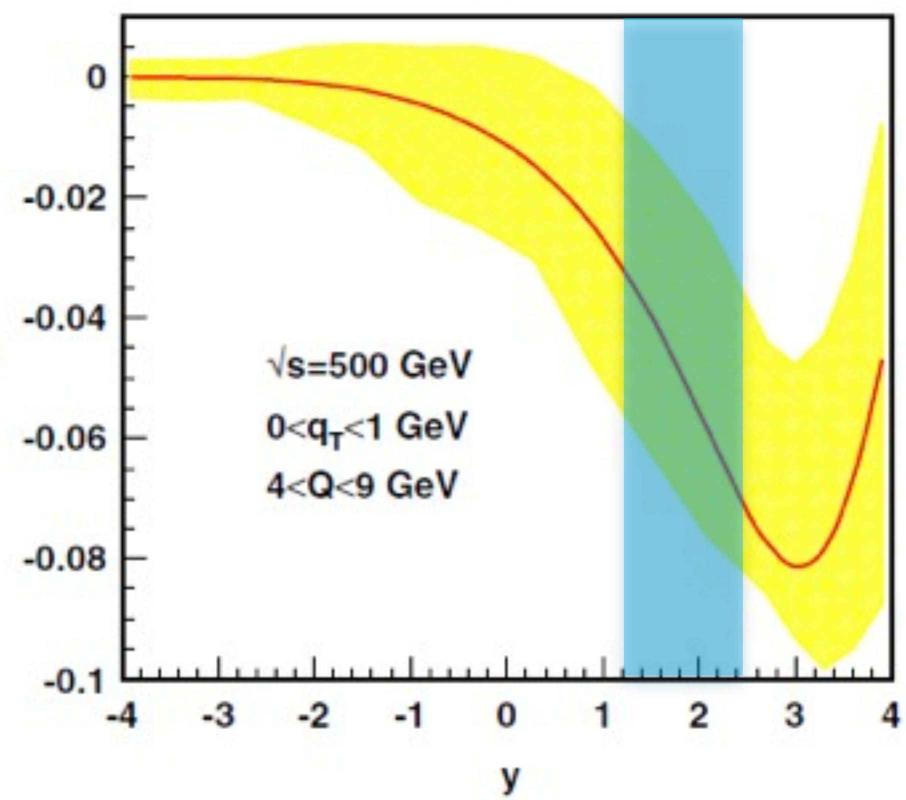
Sivers in Drell-Yan





Feasibility studies detecting di-muons with the new FVTX and the existing PHENIX muon arms ongoing





Present muon arm acceptance

Many open questions

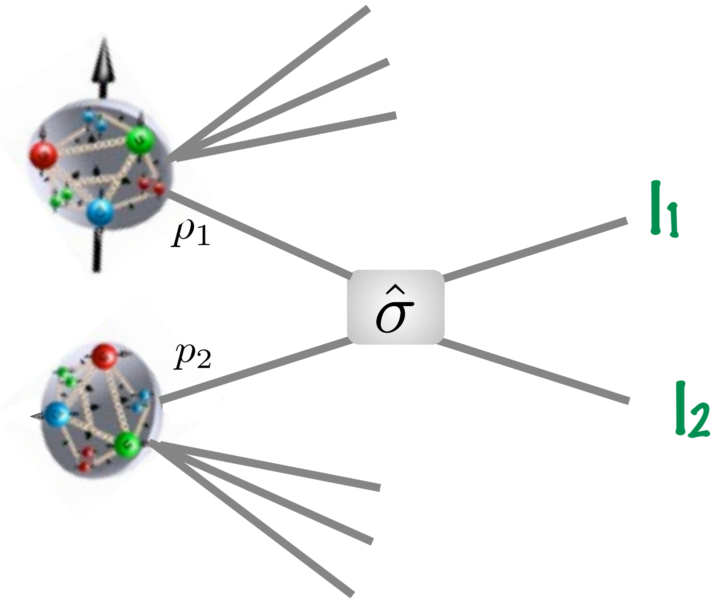
- Which effect generates those large transverse asymmetries?
- Can we access the initial state interaction (Sivers) and final state Interaction (Transversity x Collins) separately in hadron reaction?
- How is the factorization broken in hadron reactions?
- What asymmetries are generated by Transversity times IFF in forward direction?
- Does the Sivers effect generate opposite sign in SIDIS and DY, and which is its kinematic mapping?

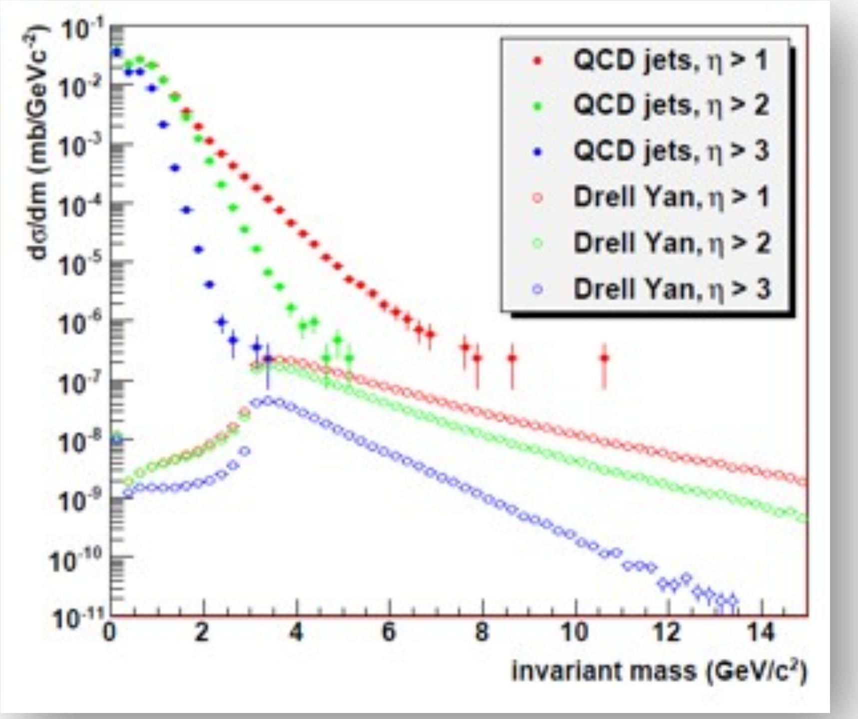
Many open questions

Forward sPHENIX

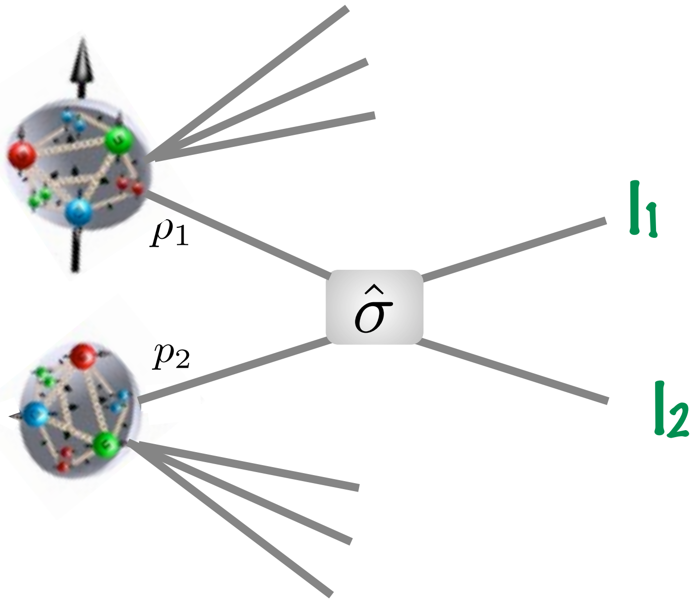
- Which effect generates those large transverse
- ...te interaction (Sivers) and ... ately in hadr...
- How is ...
- What a... nes IFF in f...
- Does the Sivers effect generate opposite sign in SIDIS and DY, and which is its kinematic mapping?

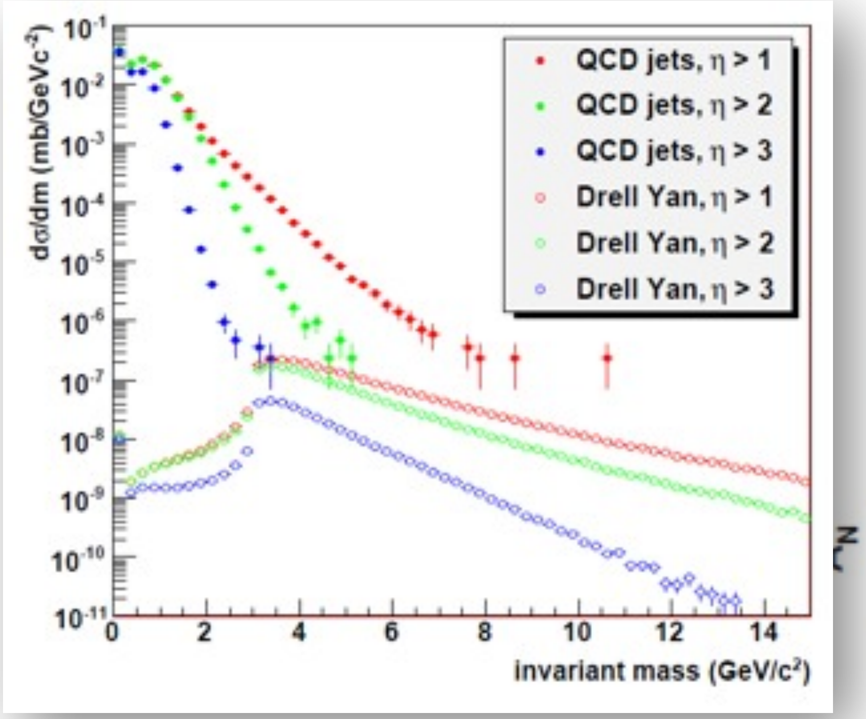
Sivers in Drell-Yan

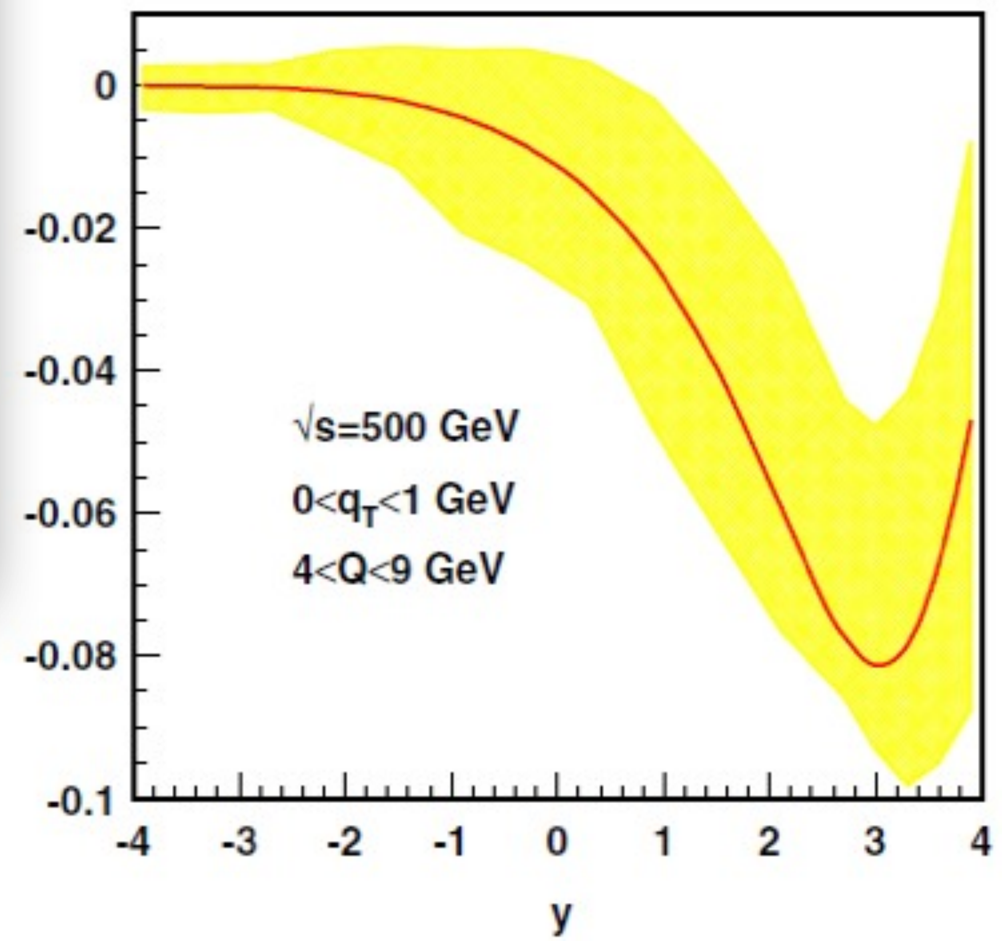




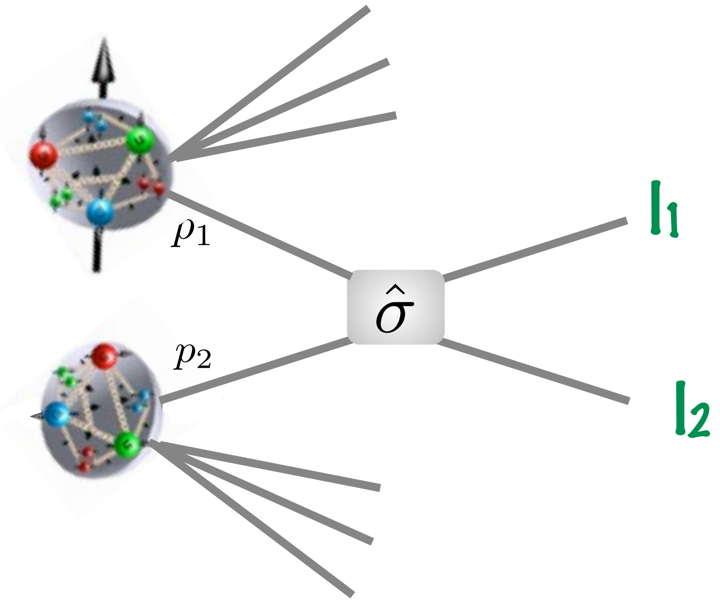
Sivers in Drell-Yan

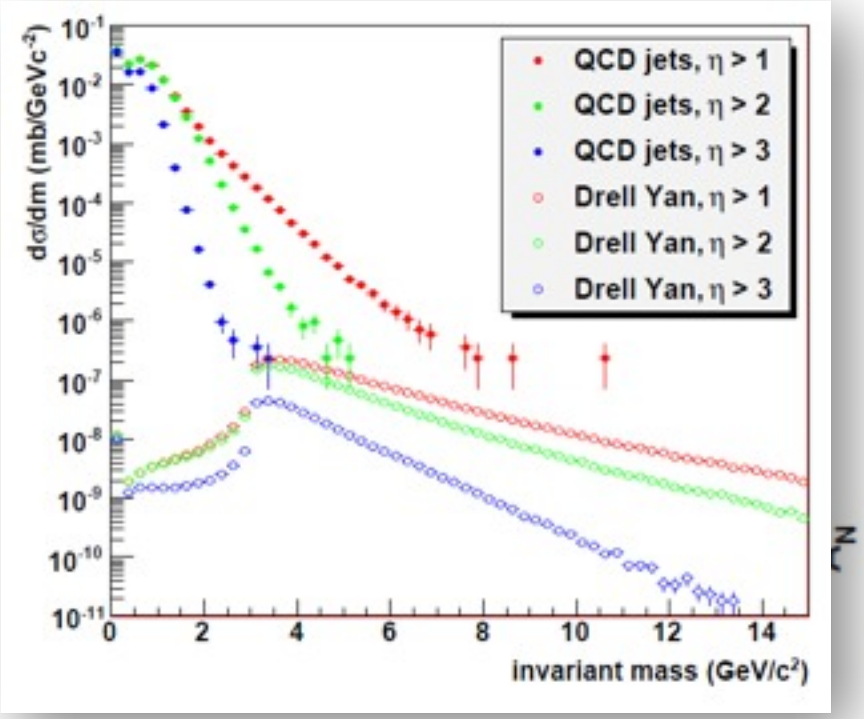


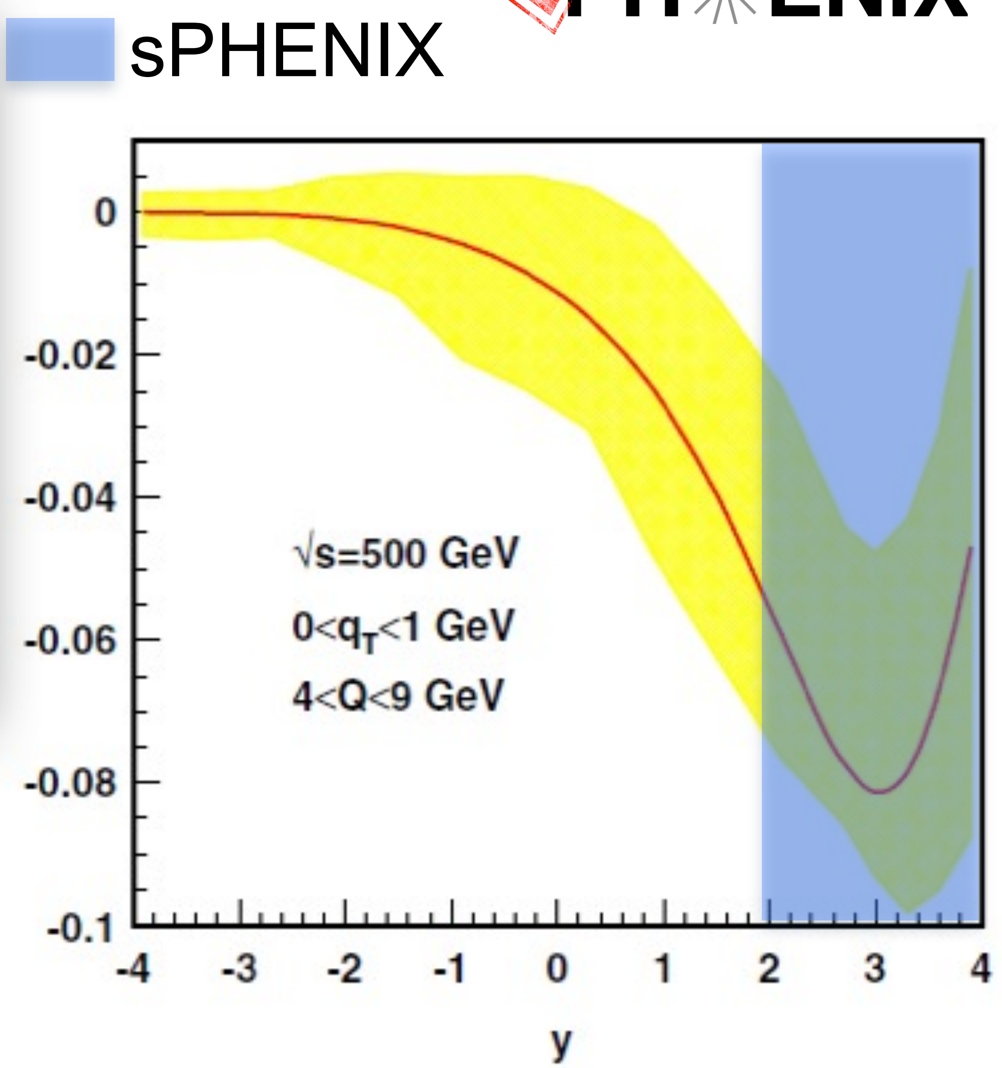




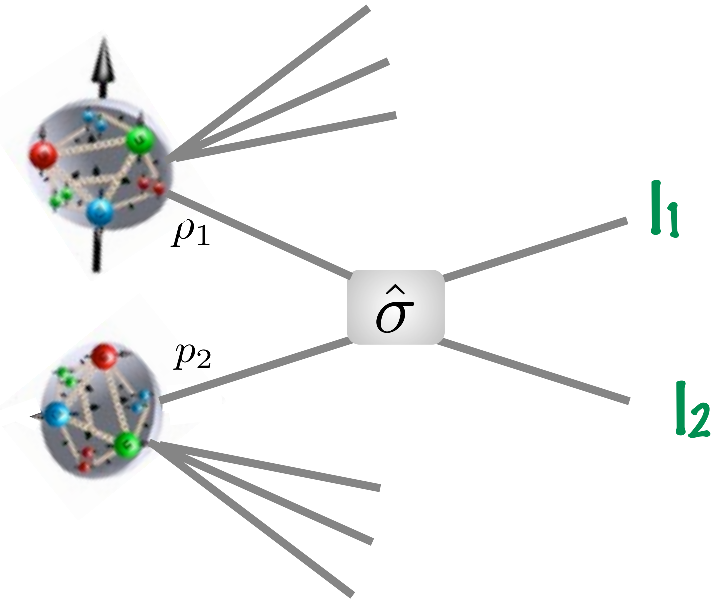
Sivers in Drell-Yan

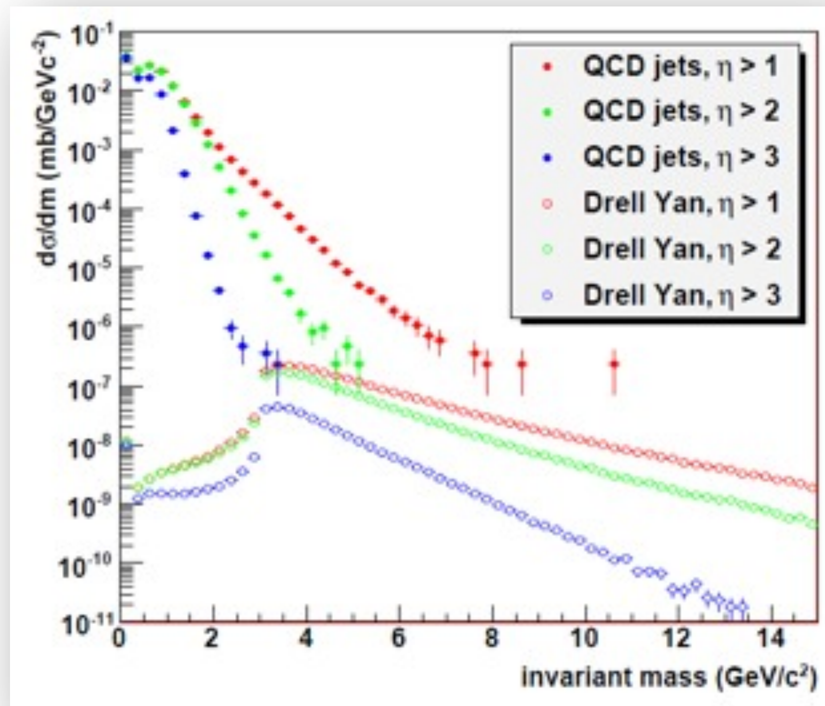


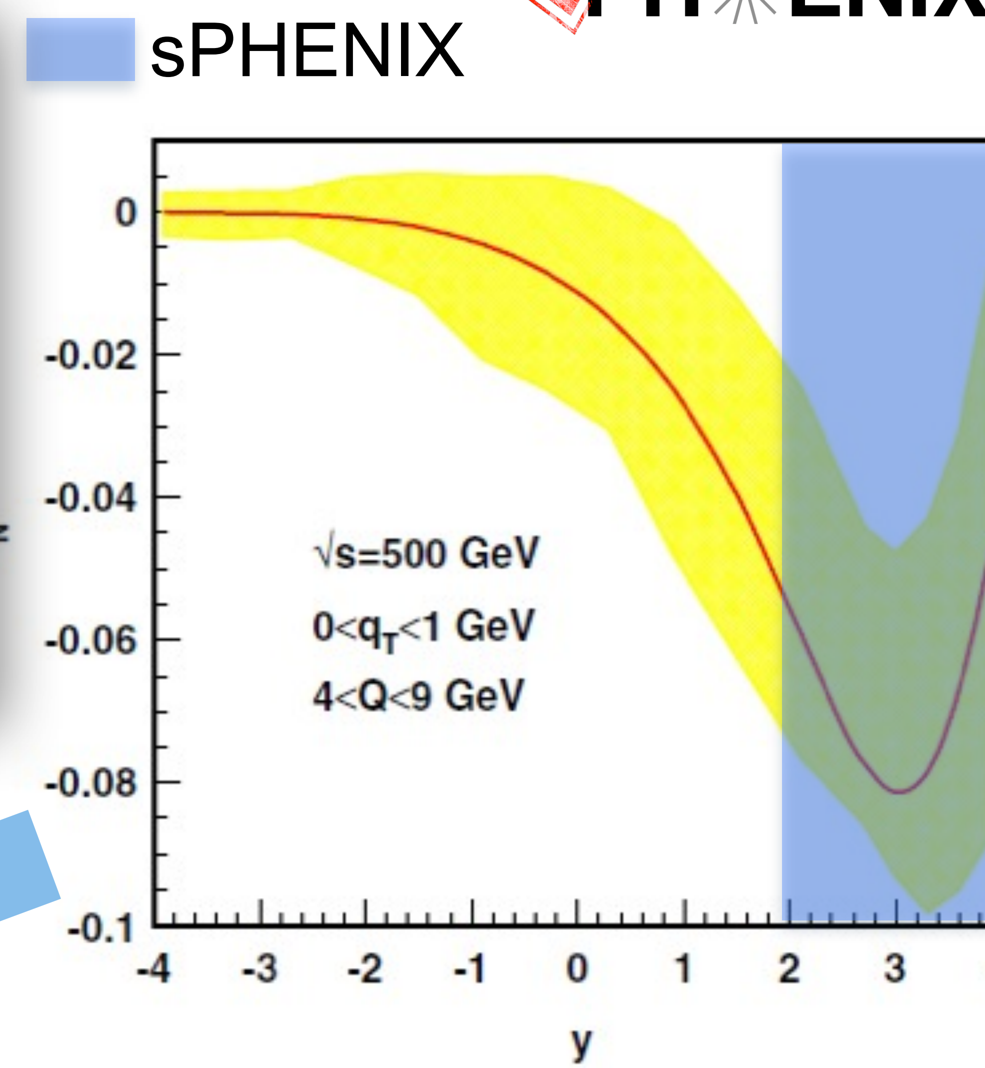




Sivers in Drell-Yan



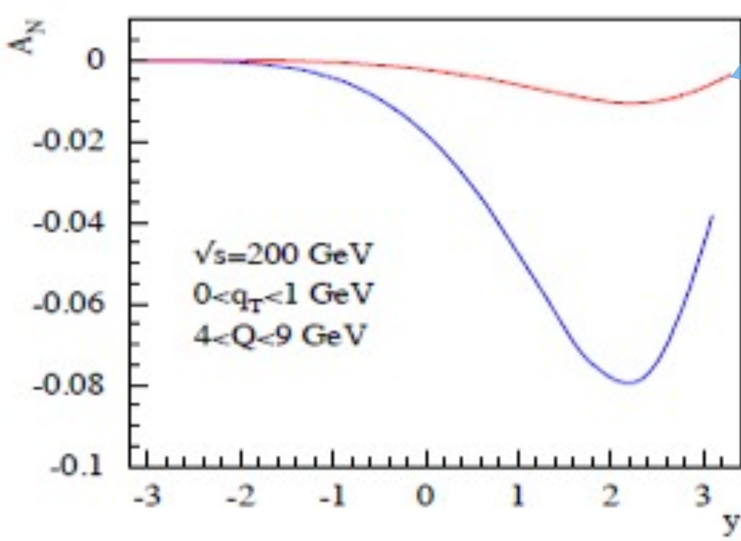




S. Mert Aybat, Alexei Prokudin, and Ted C. Rogers
arXiv:1112.4423 [hep-ph]

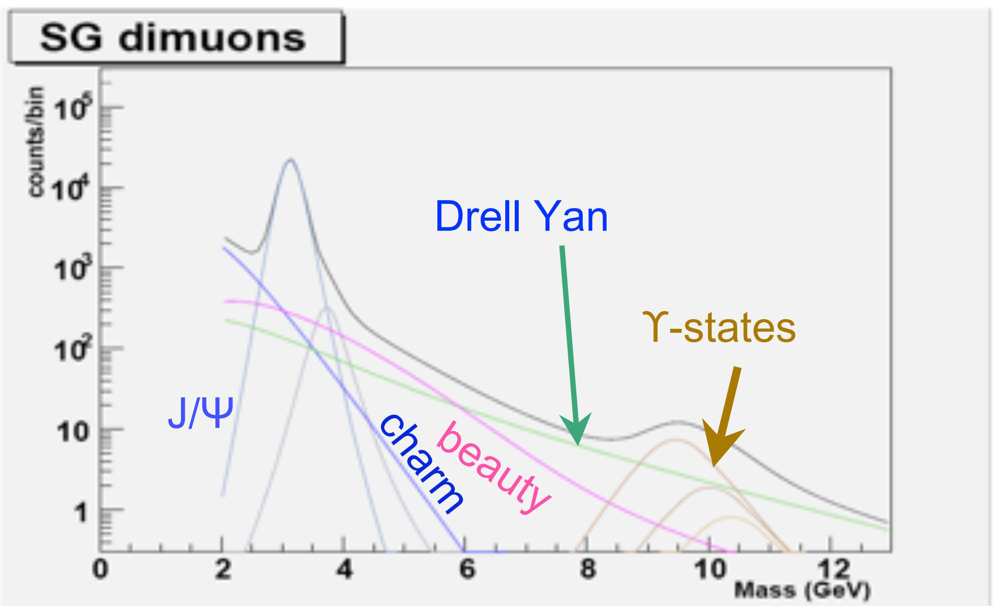
Zhong-Bo Kang and Jian-Wei Qiu
Phys. Lett. B 713, 273 (2012)

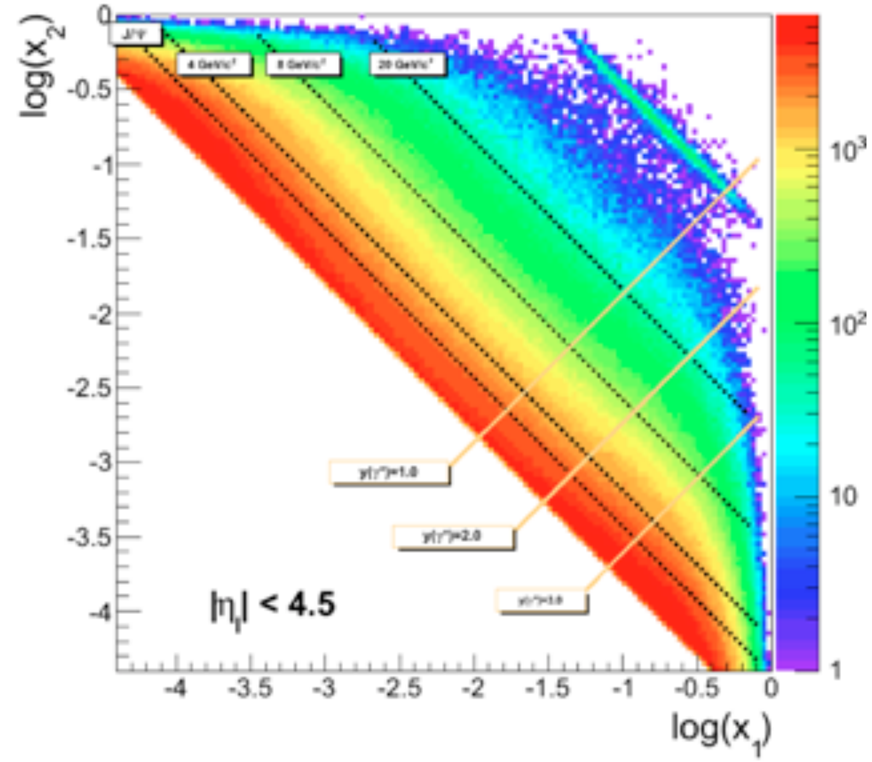
Sivers evolution

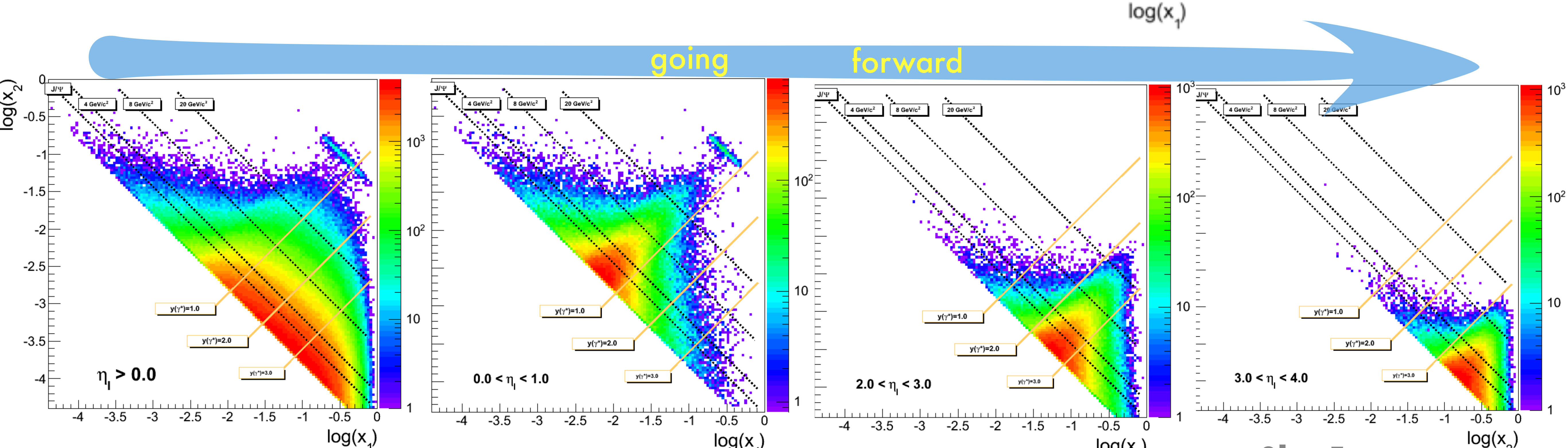


Will provide quantitative information on Sivers evolution

Mapping the Sivers mechanism

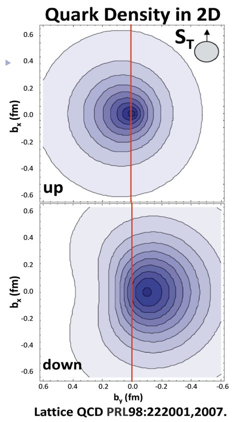




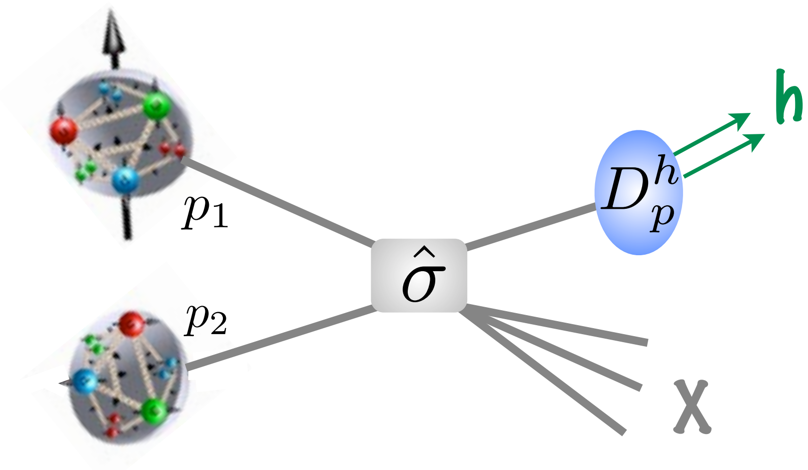


Sivers vs. Collins

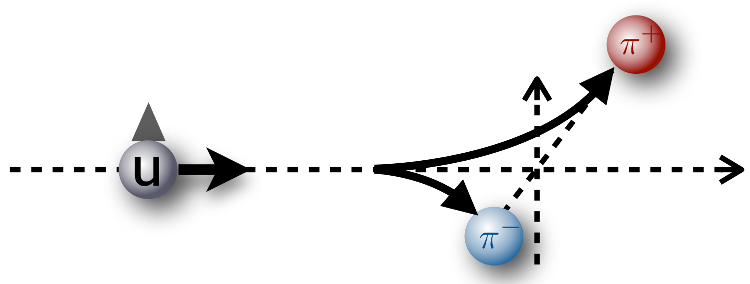
Sivers mechanism



+ FSI + ISI

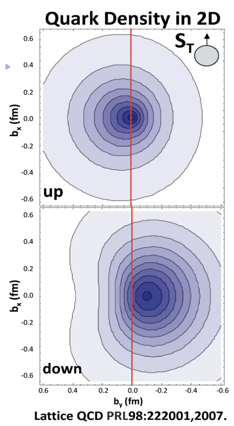


Collins mechanism



Sivers vs. Collins

Sivers mechanism



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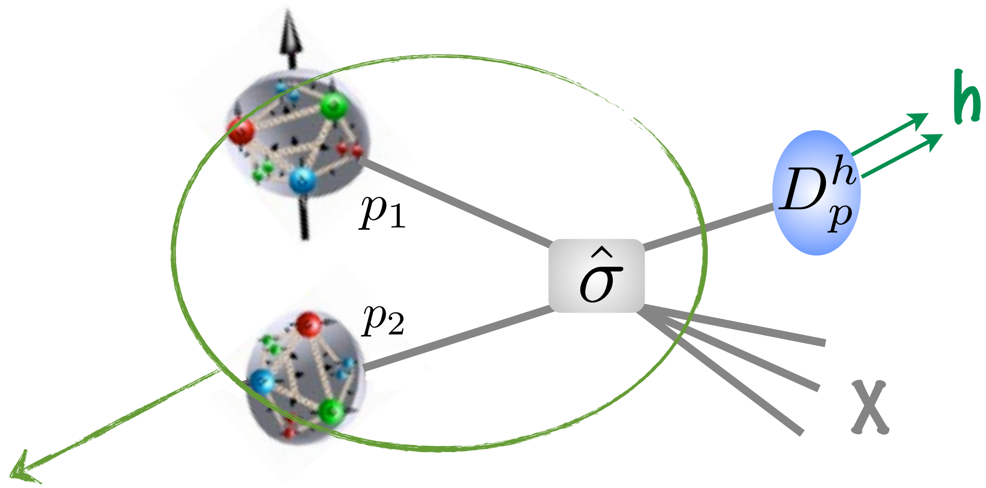
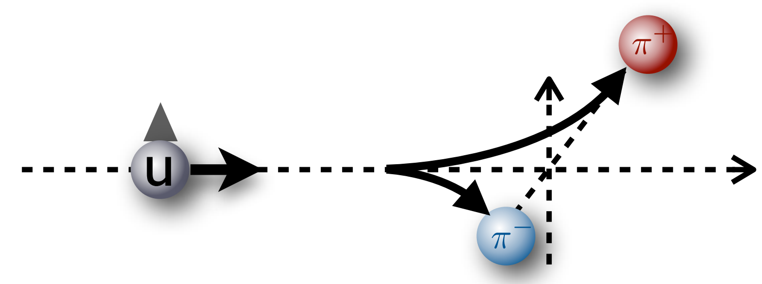


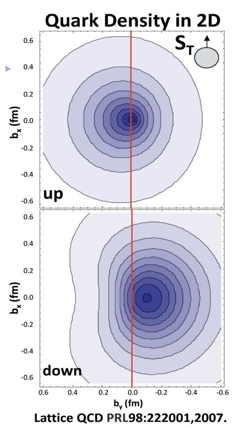
determines the direction of the outgoing quark
>> the direction of the jet

Collins mechanism

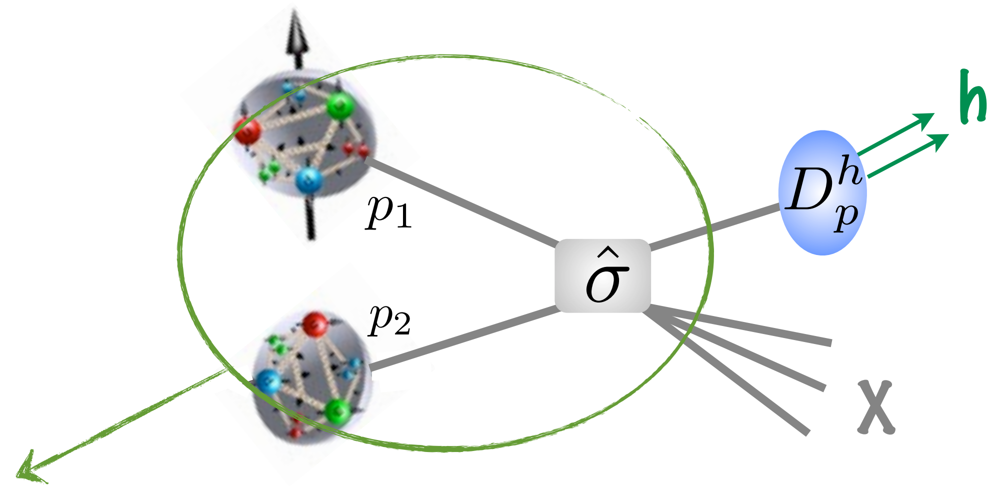


Sivers vs. Collins

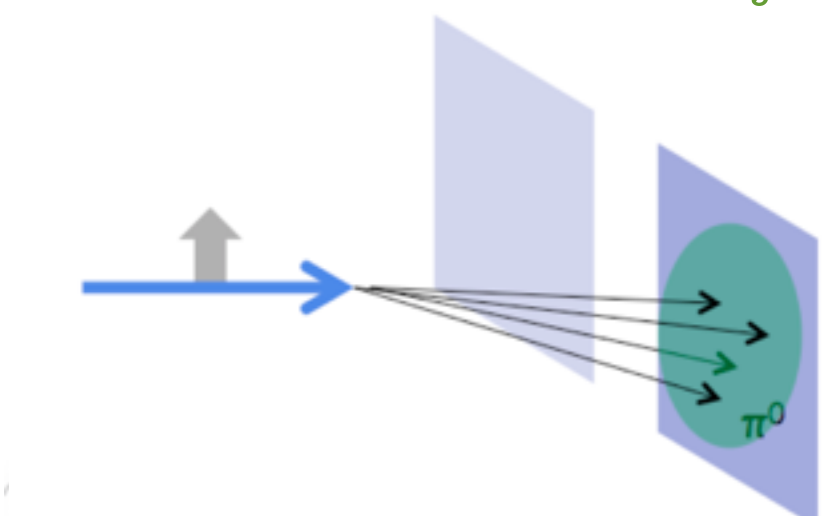
Sivers mechanism



+ FSI + ISI

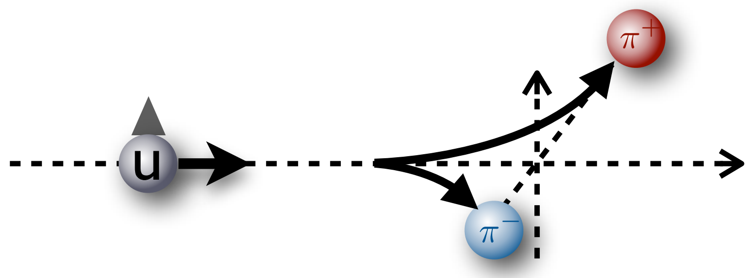


determines the direction of the outgoing quark
>> the direction of the jet



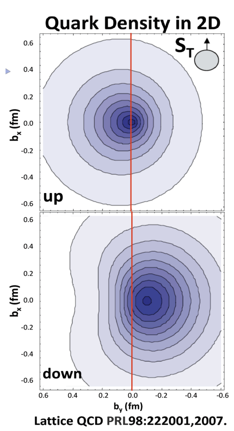
Jet asymmetry

Collins mechanism

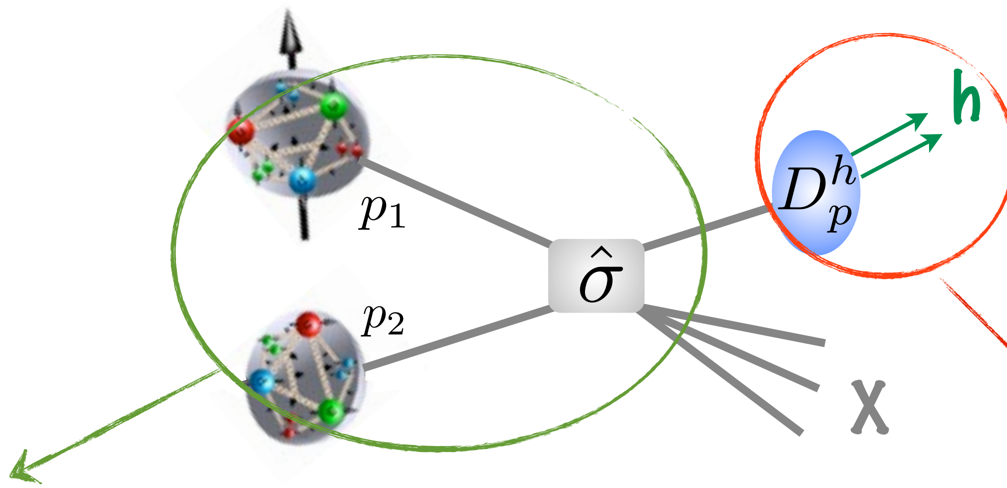


Sivers vs. Collins

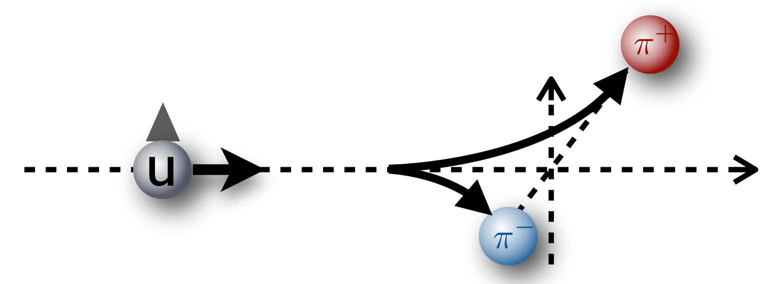
Sivers mechanism



+ FSI + ISI

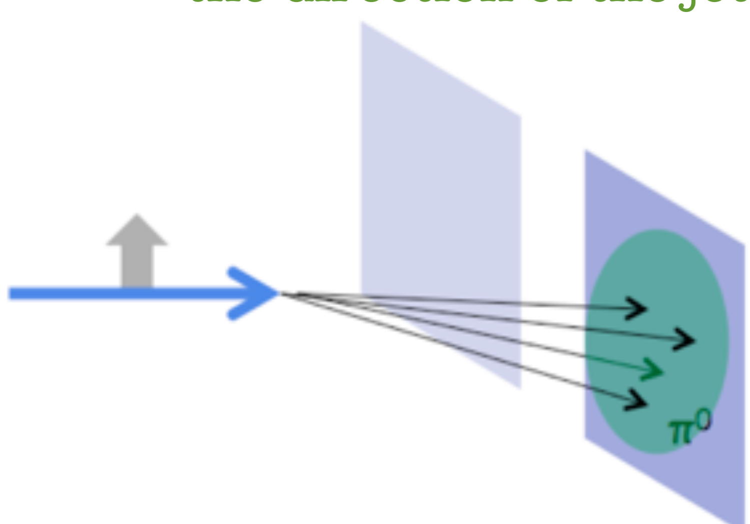


Collins mechanism



determines the direction of the outgoing quark
>> the direction of the jet

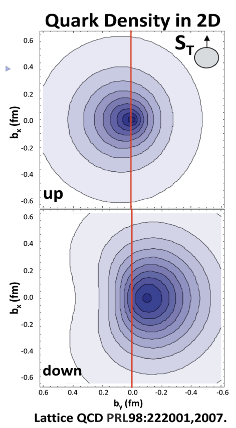
determines the
hadron distribution within the jet



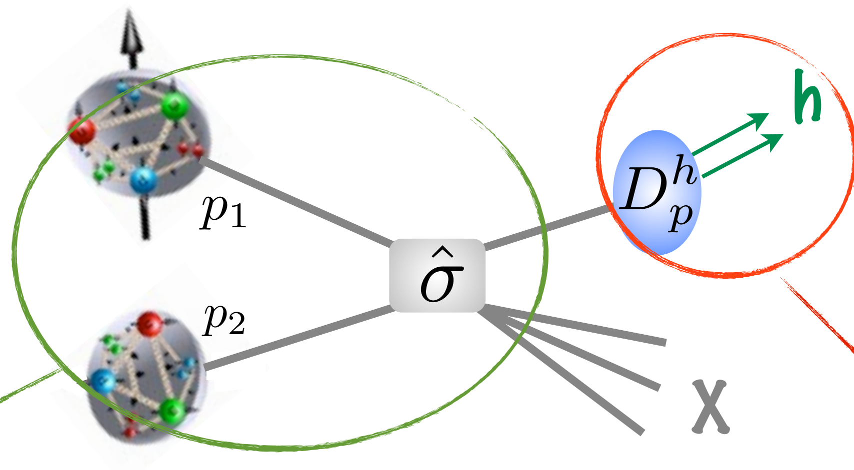
Jet asymmetry

Sivers vs. Collins

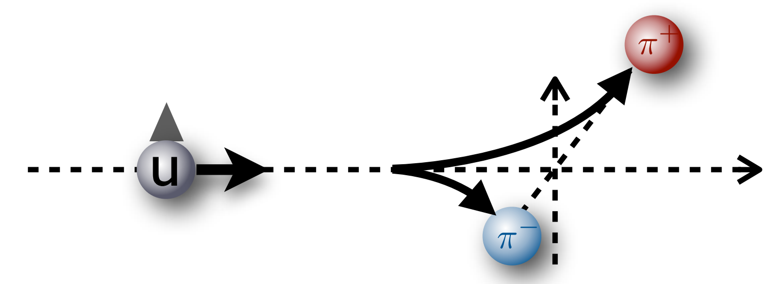
Sivers mechanism



+ FSI + ISI

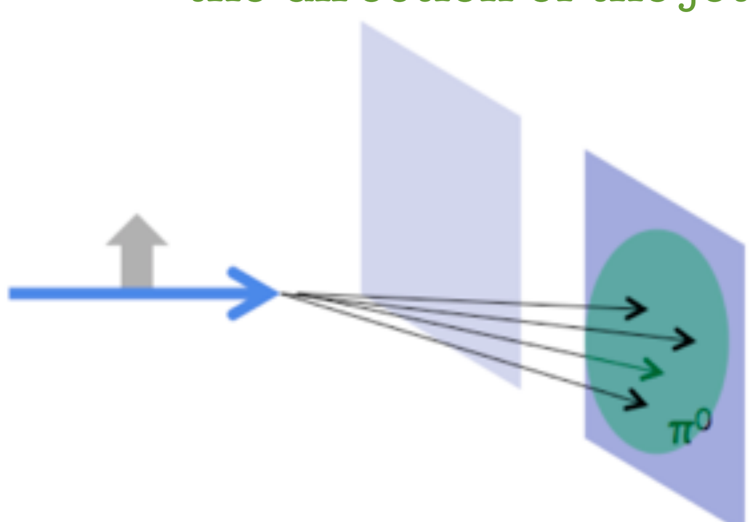


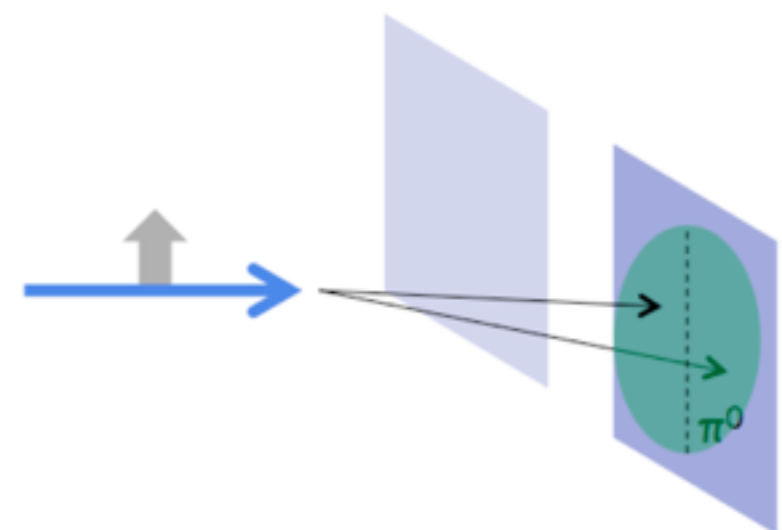
Collins mechanism



determines the direction of the outgoing quark
>> the direction of the jet

determines the
hadron distribution within the jet

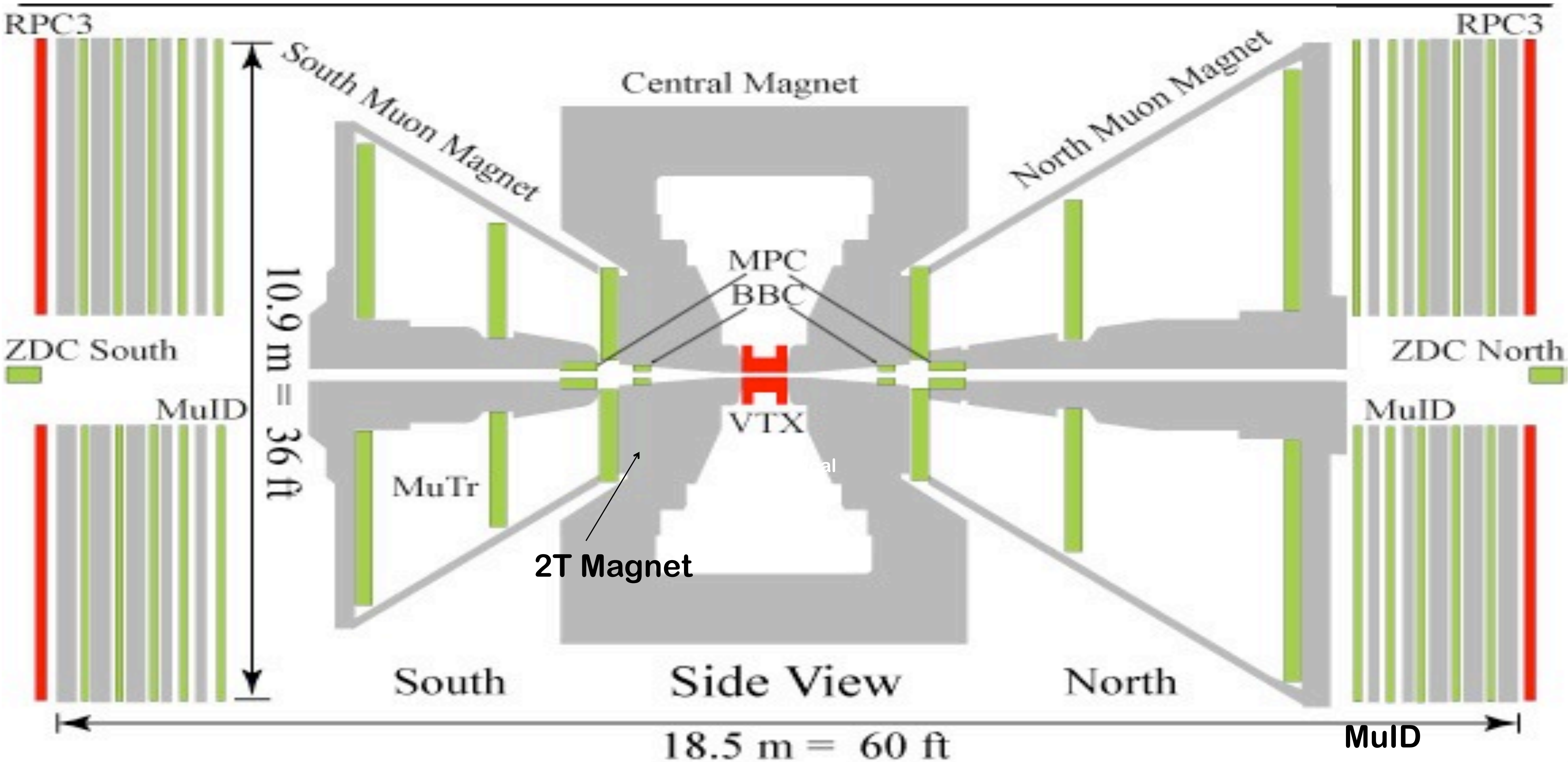




Jet asymmetry

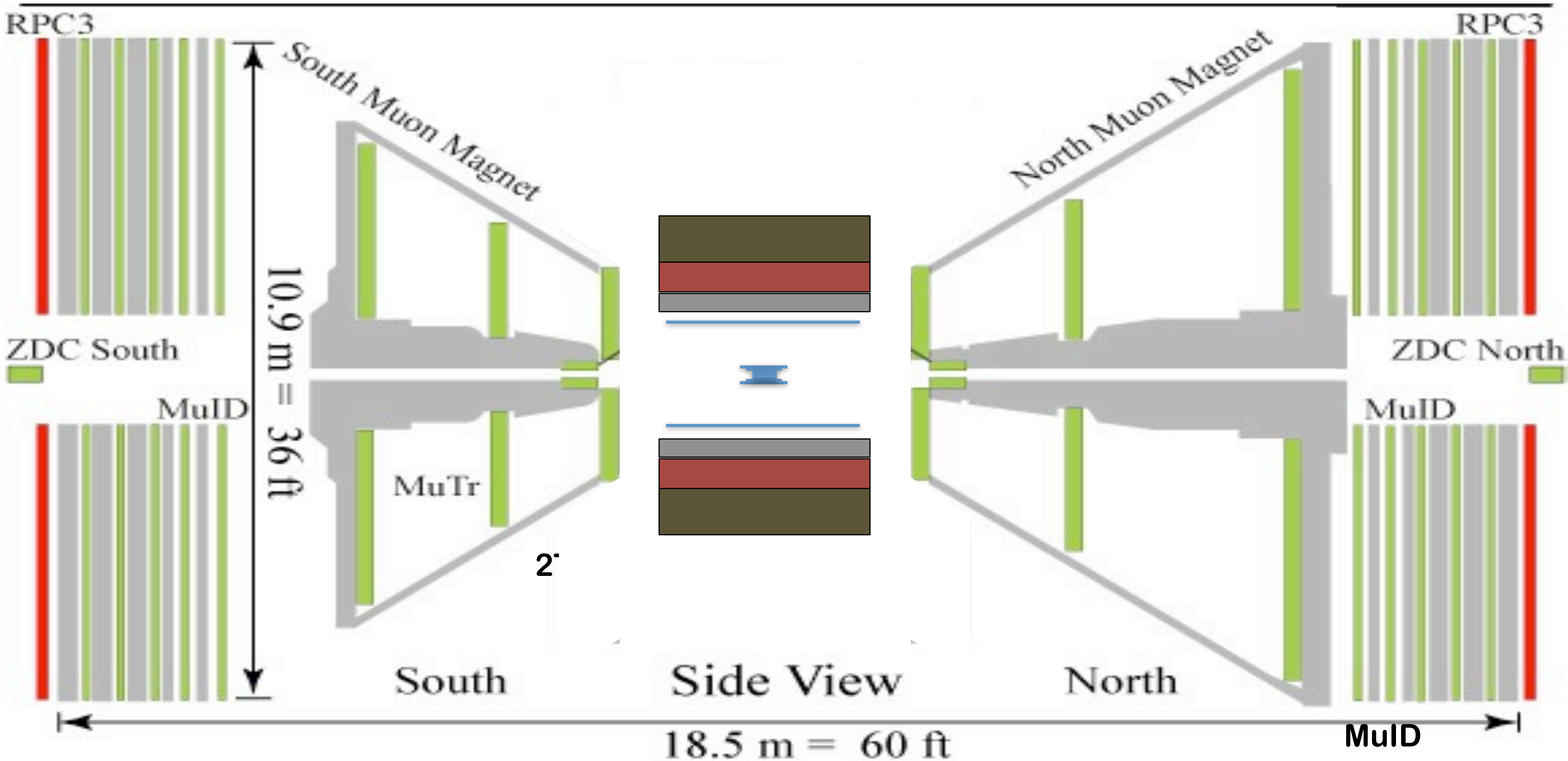
Hadron asymmetry within a Jet

PHENIX

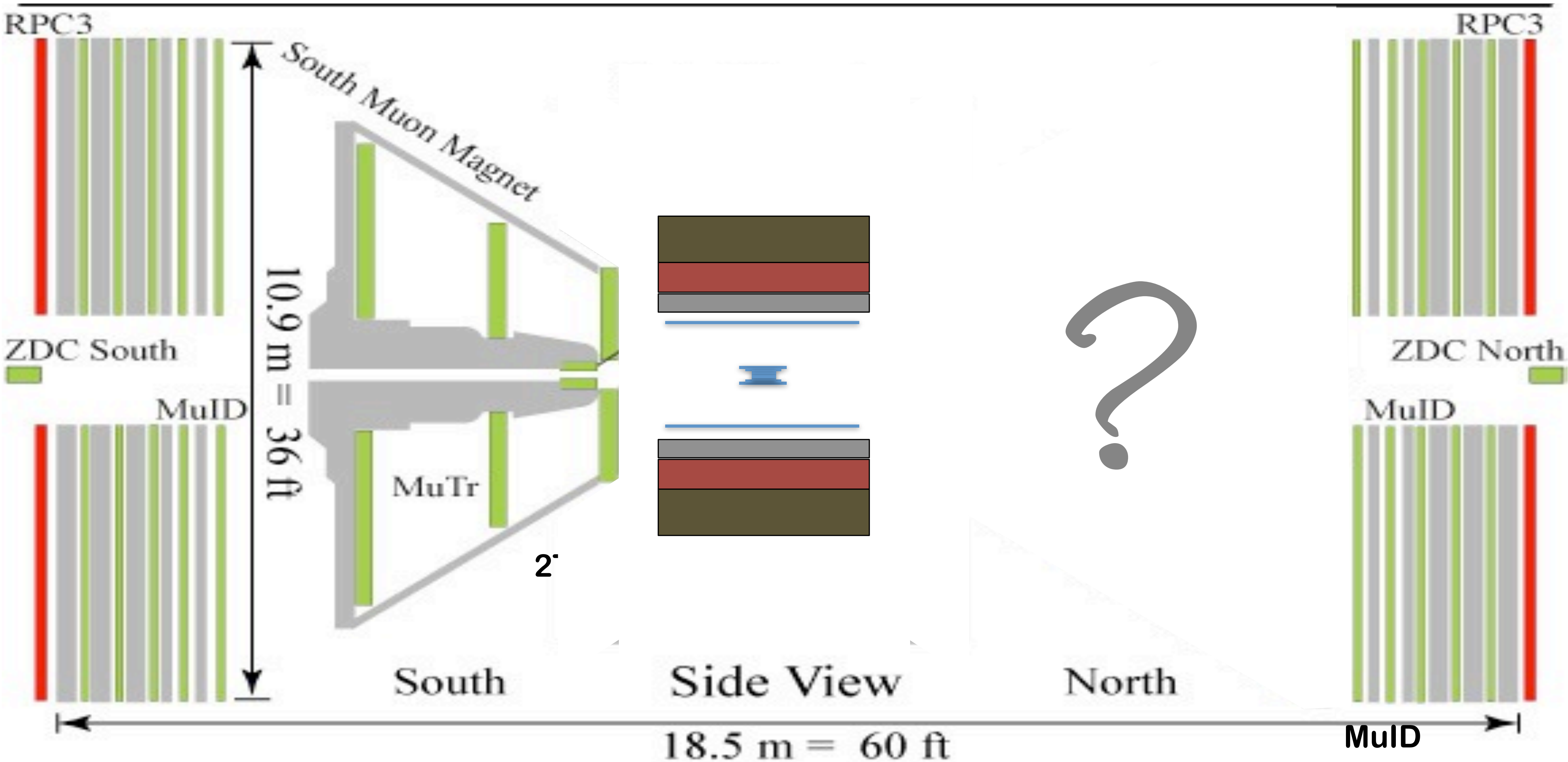


RPC3
RPC3
South Muon Magnet
Central Magnet
North Muon Magnet
10.9 m = 36 ft
MPC
BBC
ZDC South
ZDC North
MuID
MuID
VTX
MuTr
2T Magnet
South
Side View
North
18.5 m = 60 ft
MuID

sPHENIX


RPC3
RPC3
South Muon Magnet
North Muon Magnet
10.9 m = 36 ft
ZDC South
ZDC North
MuID
MuID
MuTr
2˚
South
Side View
North
18.5 m = 60 ft
MuID

FsPHENIX

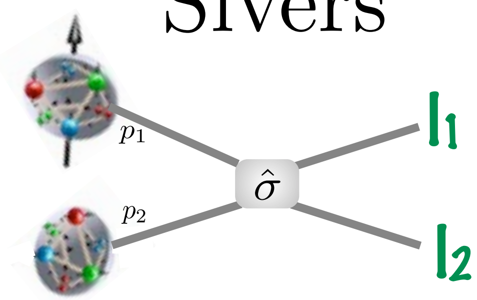


RPC3
South Muon Magnet
RPC3
10.9 m = 36 ft
ZDC South
ZDC North
MuID
MuID
MuTr
?
2˚
South
Side View
North
18.5 m = 60 ft
MuID

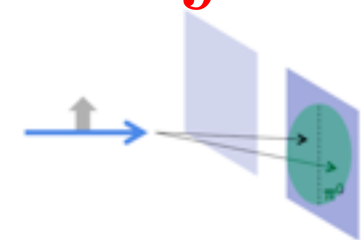
Major physics interests

Drell-Yan

Sivers

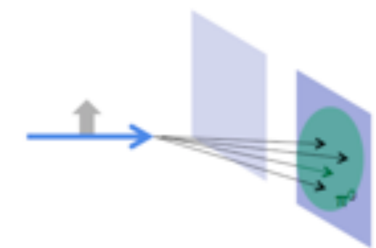


$pp \to$ jets

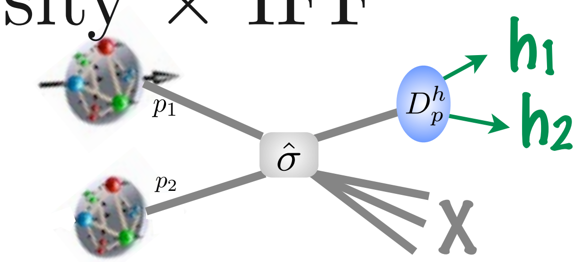


Collins

Sivers

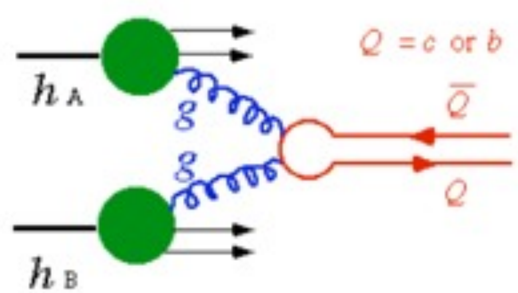


Transversity $\times$ IFF



Heavy Flavors

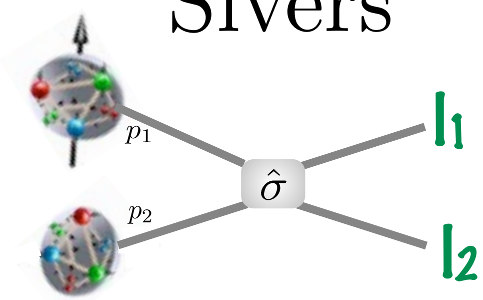
Gluon Sivers



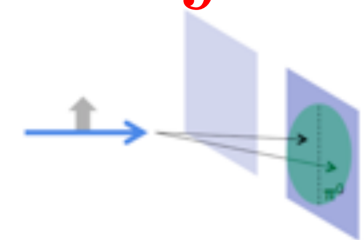
Major physics interests

Drell-Yan

Sivers

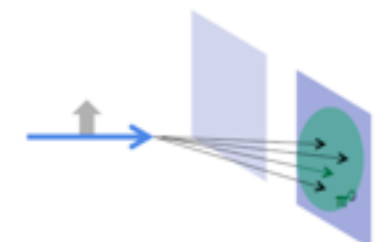


$pp \rightarrow$ jets

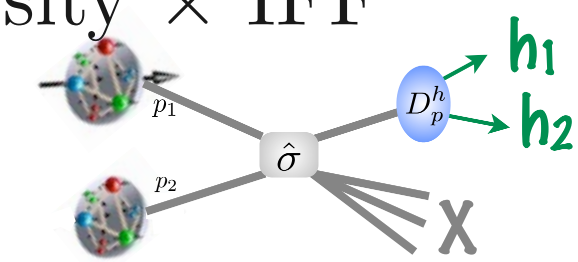


Collins

Sivers



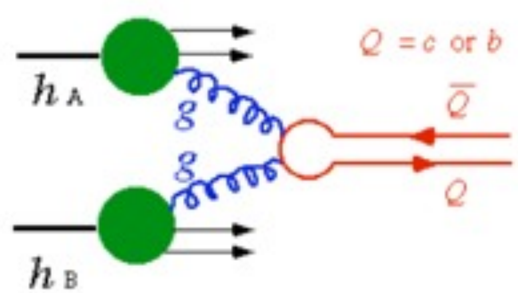
Transversity $\times$ IFF



Tracking,
Magnetic field

Heavy Flavors

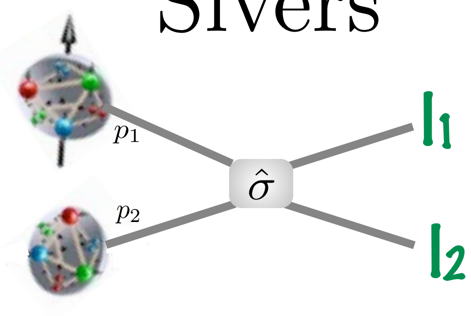
Gluon Sivers



Major physics interests

Drell-Yan

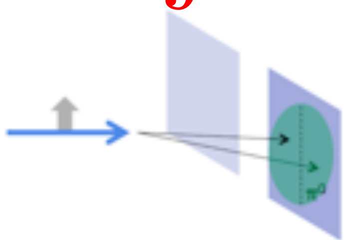
Sivers



Good electron ID,
hadron rejection

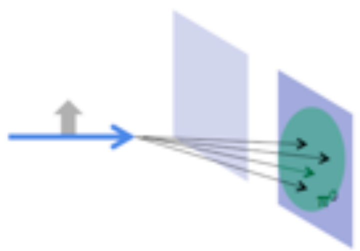
Tracking,
Magnetic field

$pp \rightarrow$ jets

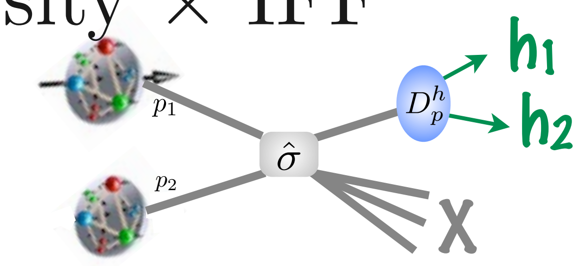


Collins

Sivers

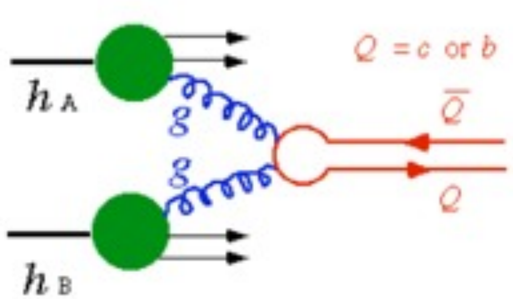


Transversity $\times$ IFF



Heavy Flavors

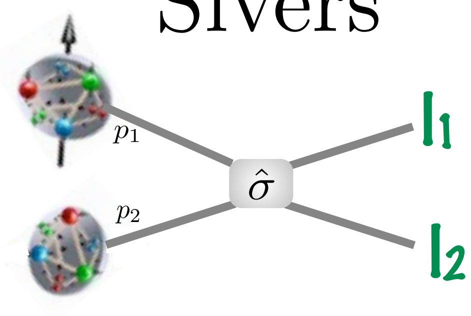
Gluon Sivers



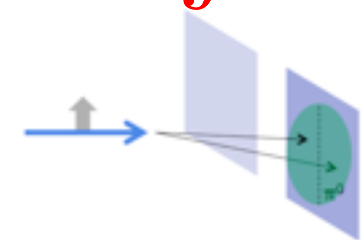
Major physics interests

Drell-Yan

Sivers

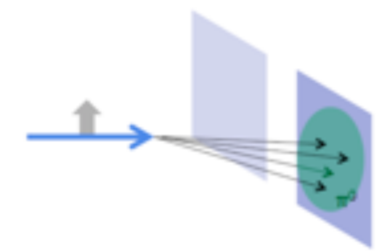


$pp \rightarrow$ jets

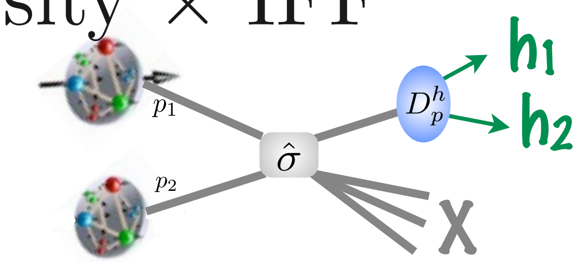


Collins

Sivers



Transversity $\times$ IFF



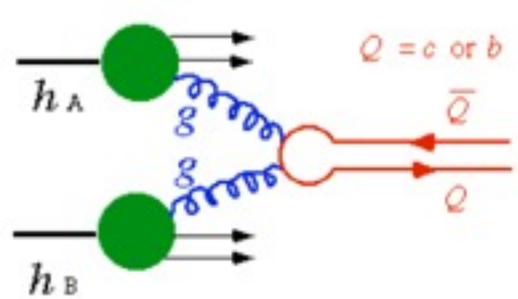
Good electron ID, hadron rejection

Tracking, Magnetic field

Good jet reconstruction

Heavy Flavors

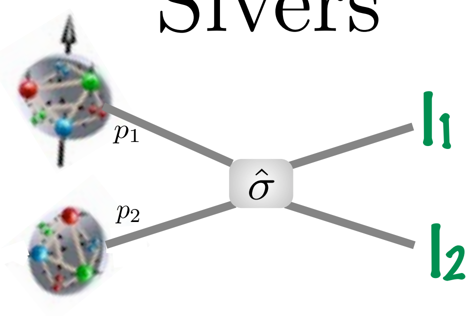
Gluon Sivers



Major physics interests

Drell-Yan

Sivers



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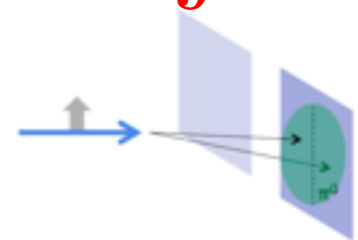
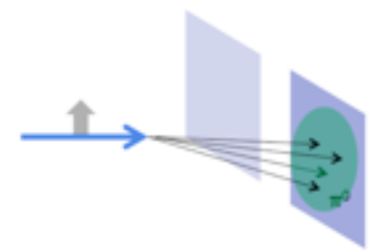
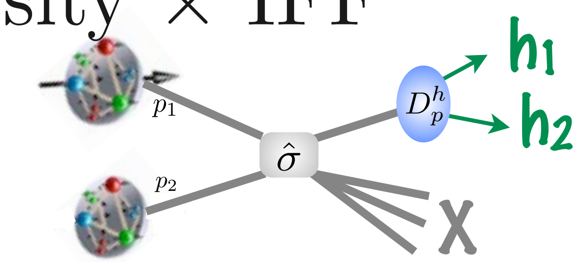


Collins

Sivers



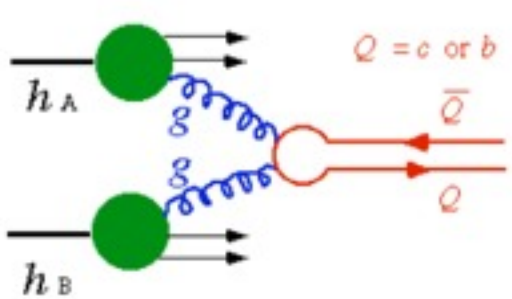
Transversity $\times$ IFF



Good hadron ID

Heavy Flavors

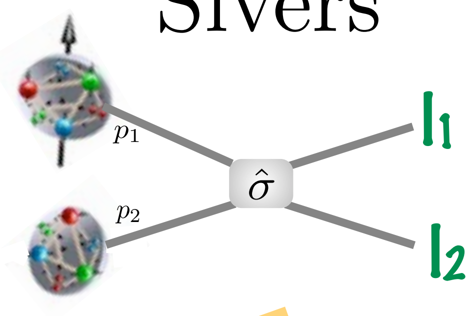
Gluon Sivers



Major physics interests

Drell-Yan

Sivers



Heavy Ion ID

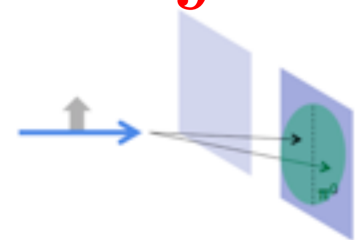
Good electron ID,
hadron rejection

Tracking,
Magnetic field

Good jet
reconstruction

$pp \to$ jets

Collins



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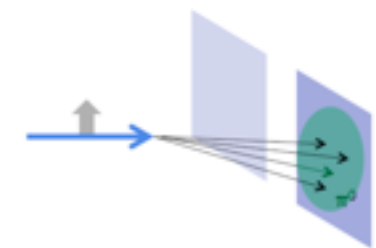
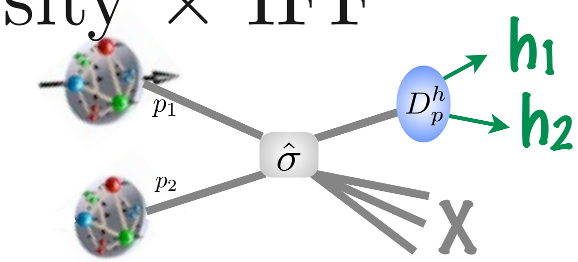


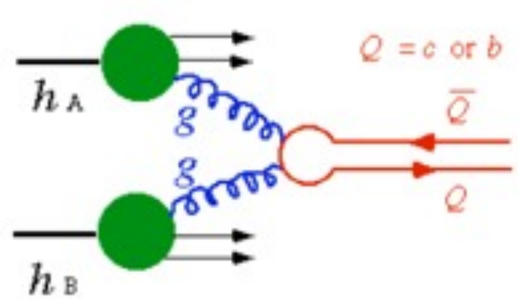
Transversity $\times$ IFF



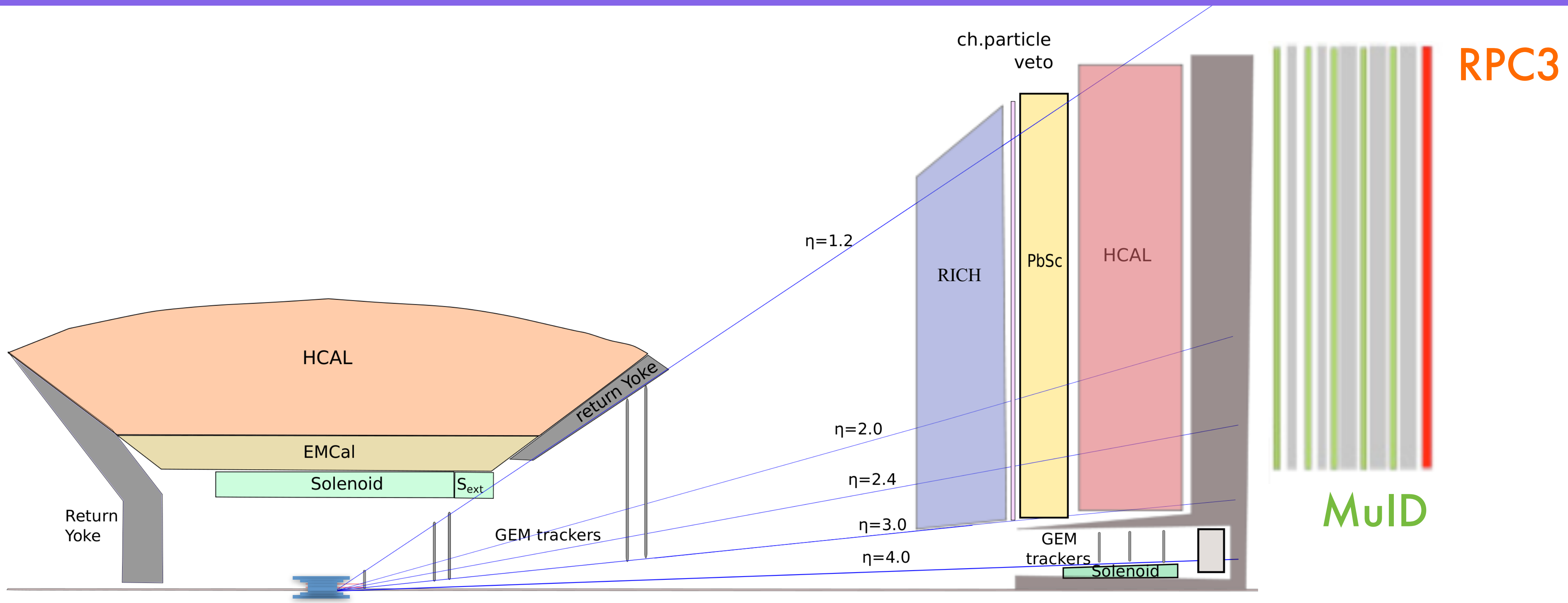
Good hadron ID

Heavy Flavors

Gluon Sivers

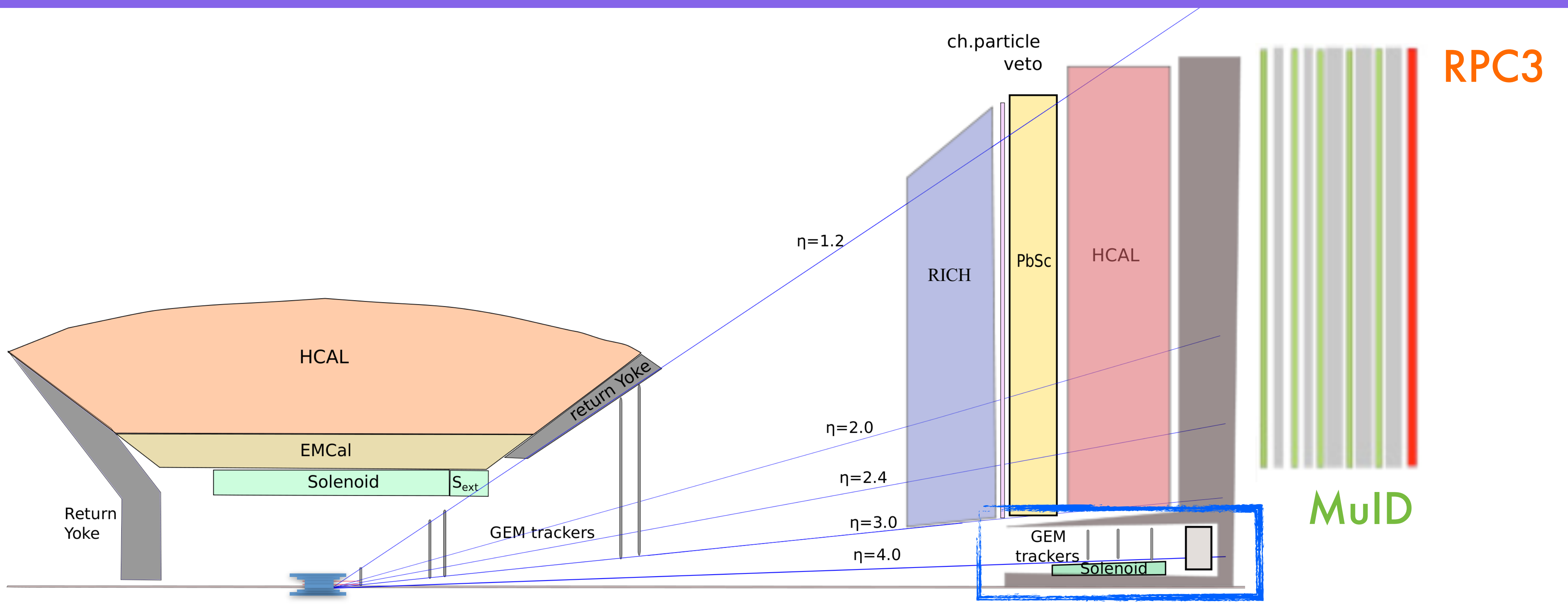


Detector concept



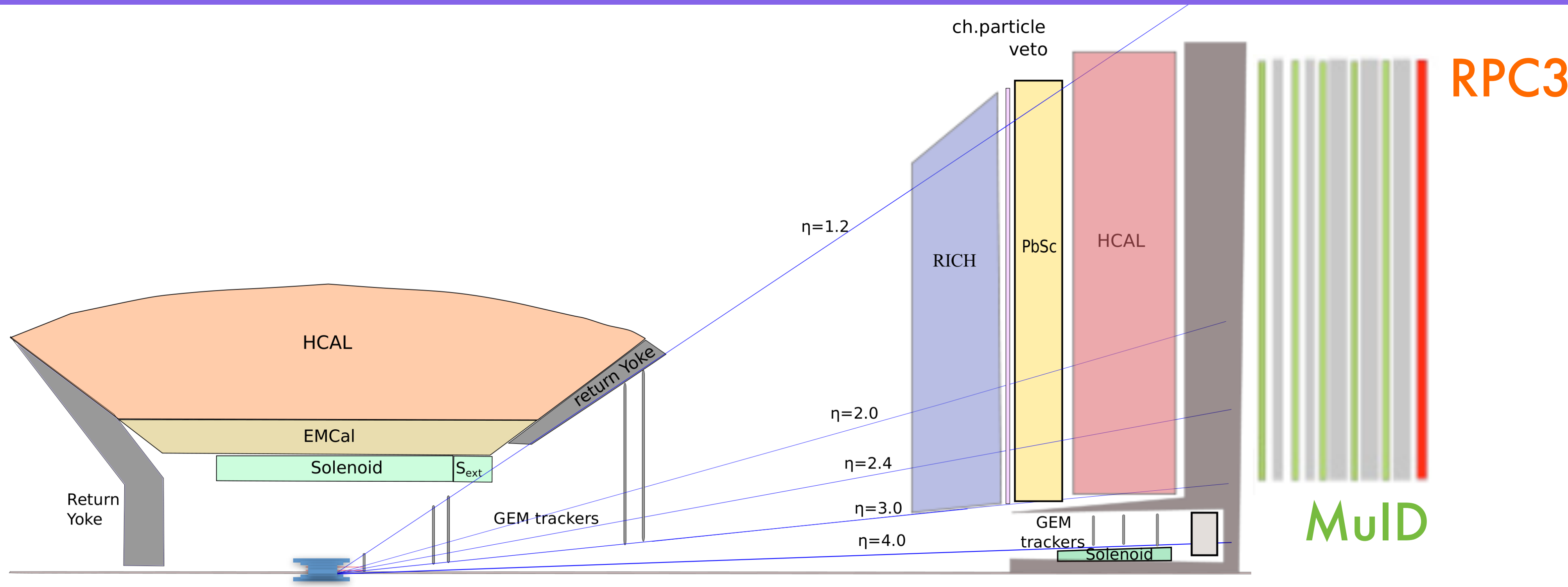
- Forward section $1.2 < \eta < 3$

Detector concept



- Forward section $1.2 < \eta < 3$
- Very forward section $3 < \eta < 4$

Detector concept

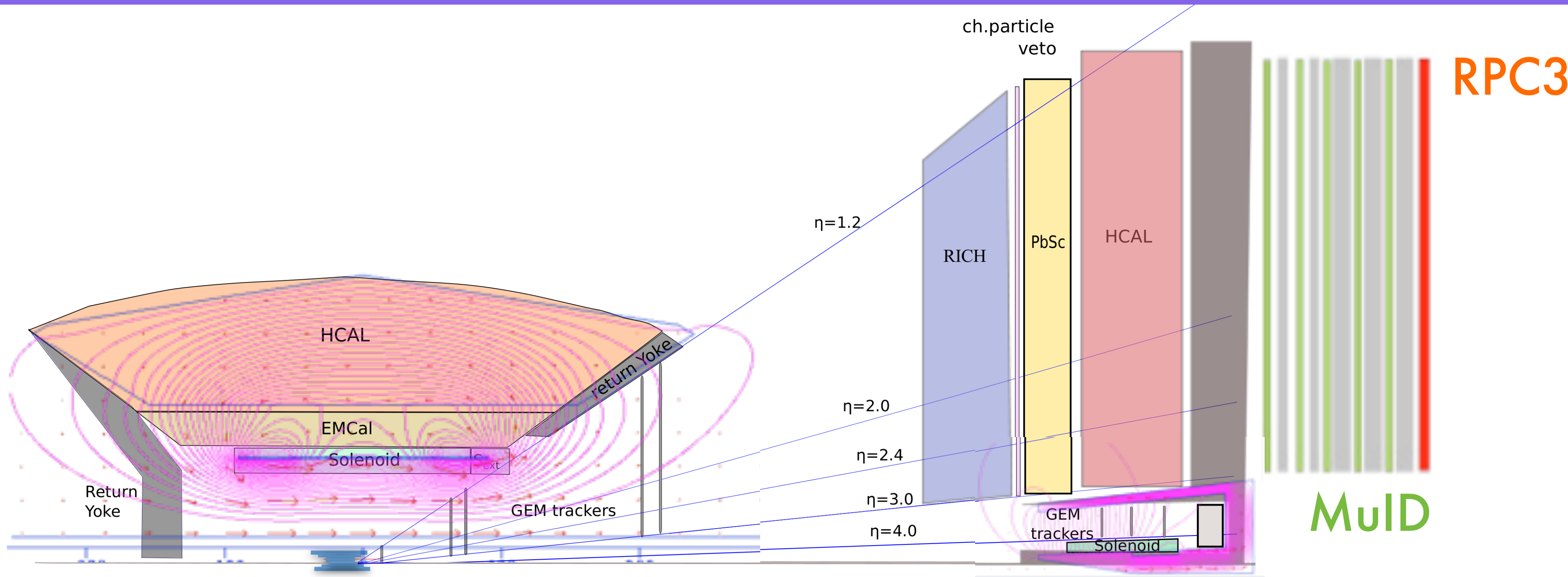


Los Alamos, RBRC

Tracking:

- Existing FVTX for vertex reconstruction and background rejection
- Diamond pixel and GEM trackers for the Forward region
- GEM trackers for the Very Forward region

Detector concept



Tracking:

Los Alamos, RBRC

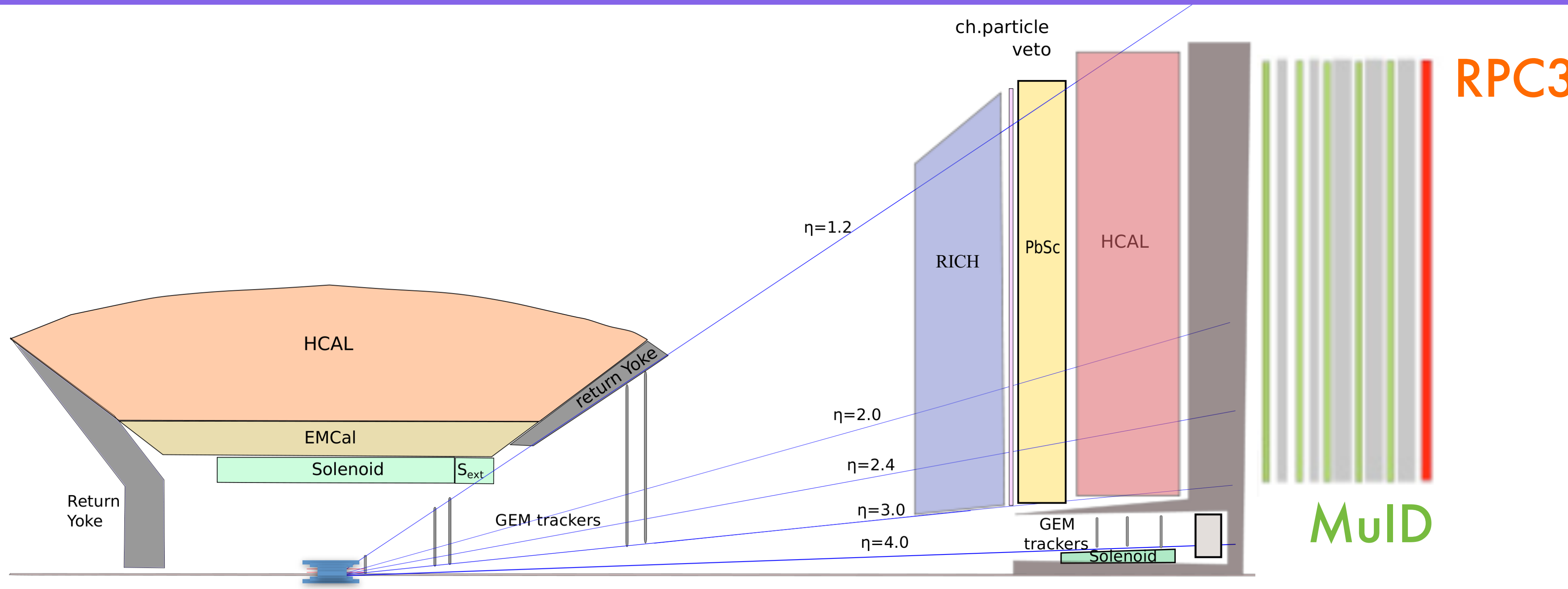
- Existing FVTX for vertex reconstruction and background rejection
- Diamond pixel and GEM trackers for the Forward region
- GEM trackers for the Very Forward region

Los Alamos, RBRC, UCR

Magnetic fields:

- Forward region: extension of the central 2T solenoid
- Very forward region: additional solenoid

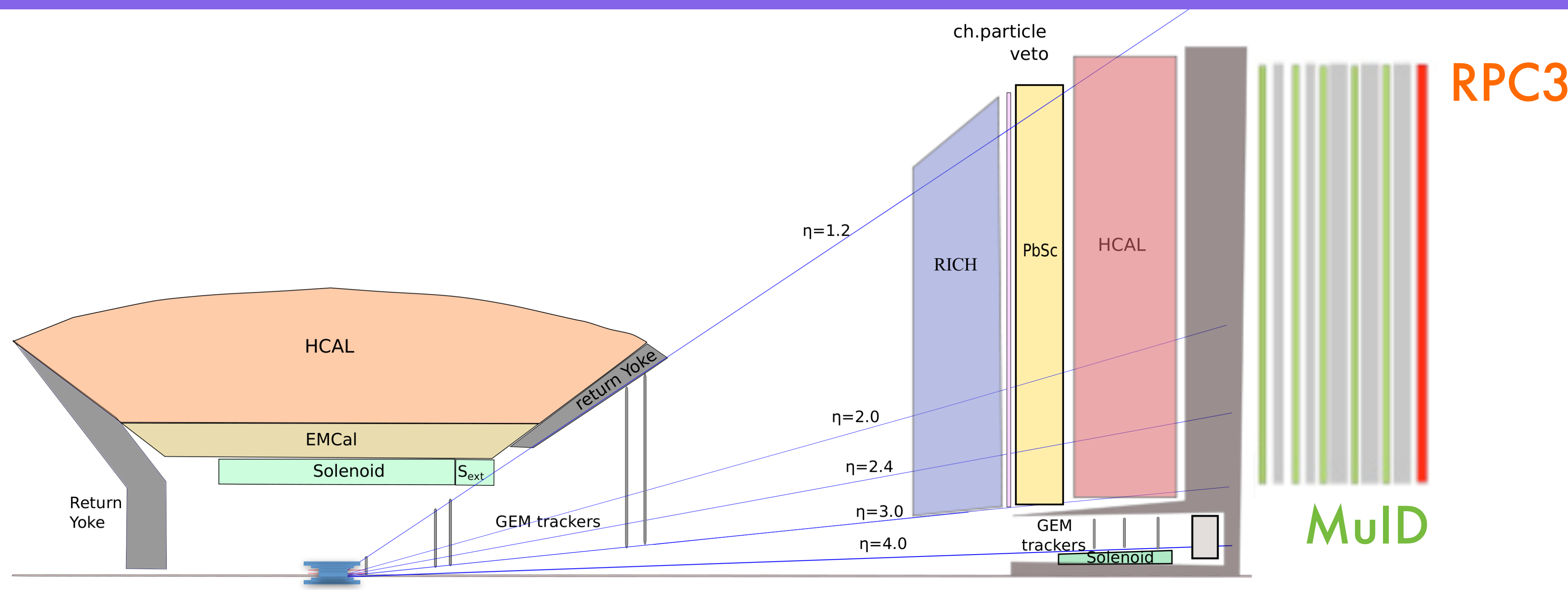
Detector concept



Jet reconstruction: **UIUC**

- Hadronic Calorimeter

Detector concept



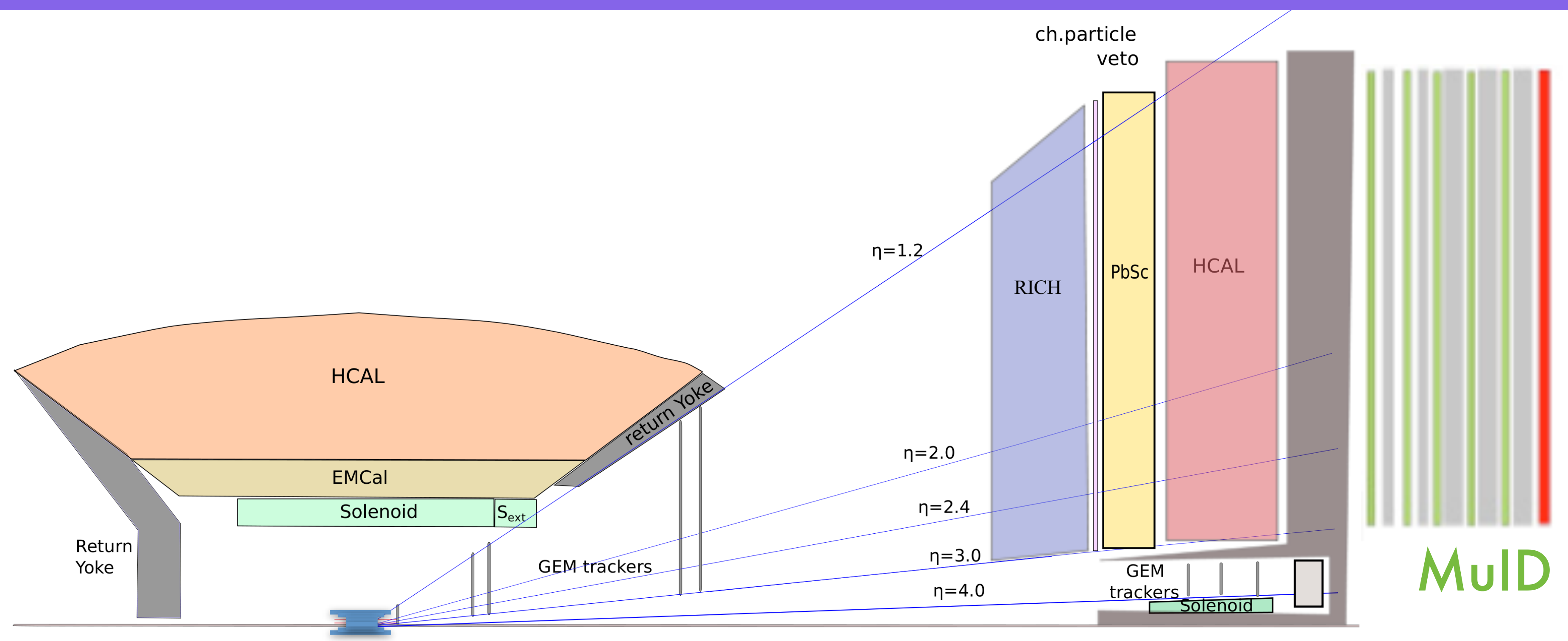
Jet reconstruction: **UIUC**

- Hadronic Calorimeter

Hadron ID **Stony Brook**

- Dual radiator Ring Imaging Cherenkov

Detector concept



Jet reconstruction: **UIUC**

- Hadronic Calorimeter

Hadron ID **Stony Brook**

- Dual radiator Ring Imaging Cherenkov

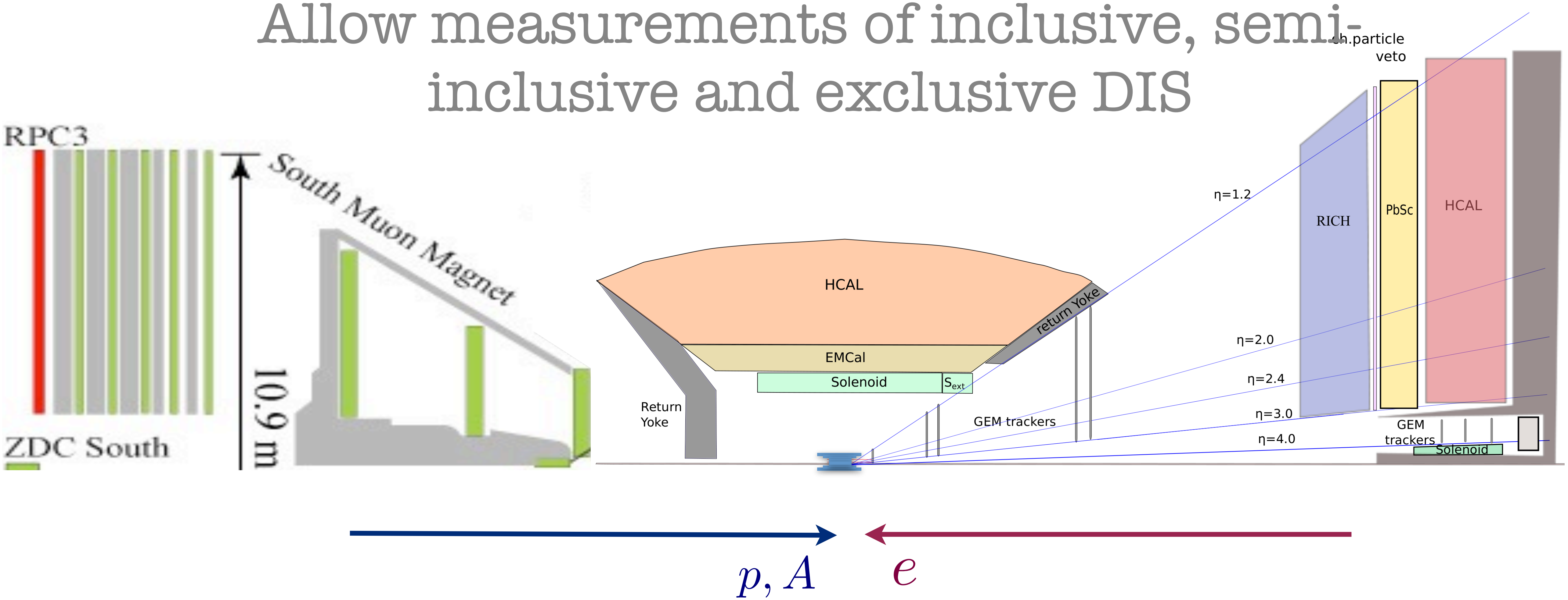
Electron ID

RBRC, ISU

- Preshower
- EM-Calorimeter :
  - Forward region: restacking of existing central Phenix Calo (5.5x5.5 cm^2)
  - Very Forward region: restacking of the MPC-EX (2.2x2.2 cm^2)

ePHENIX

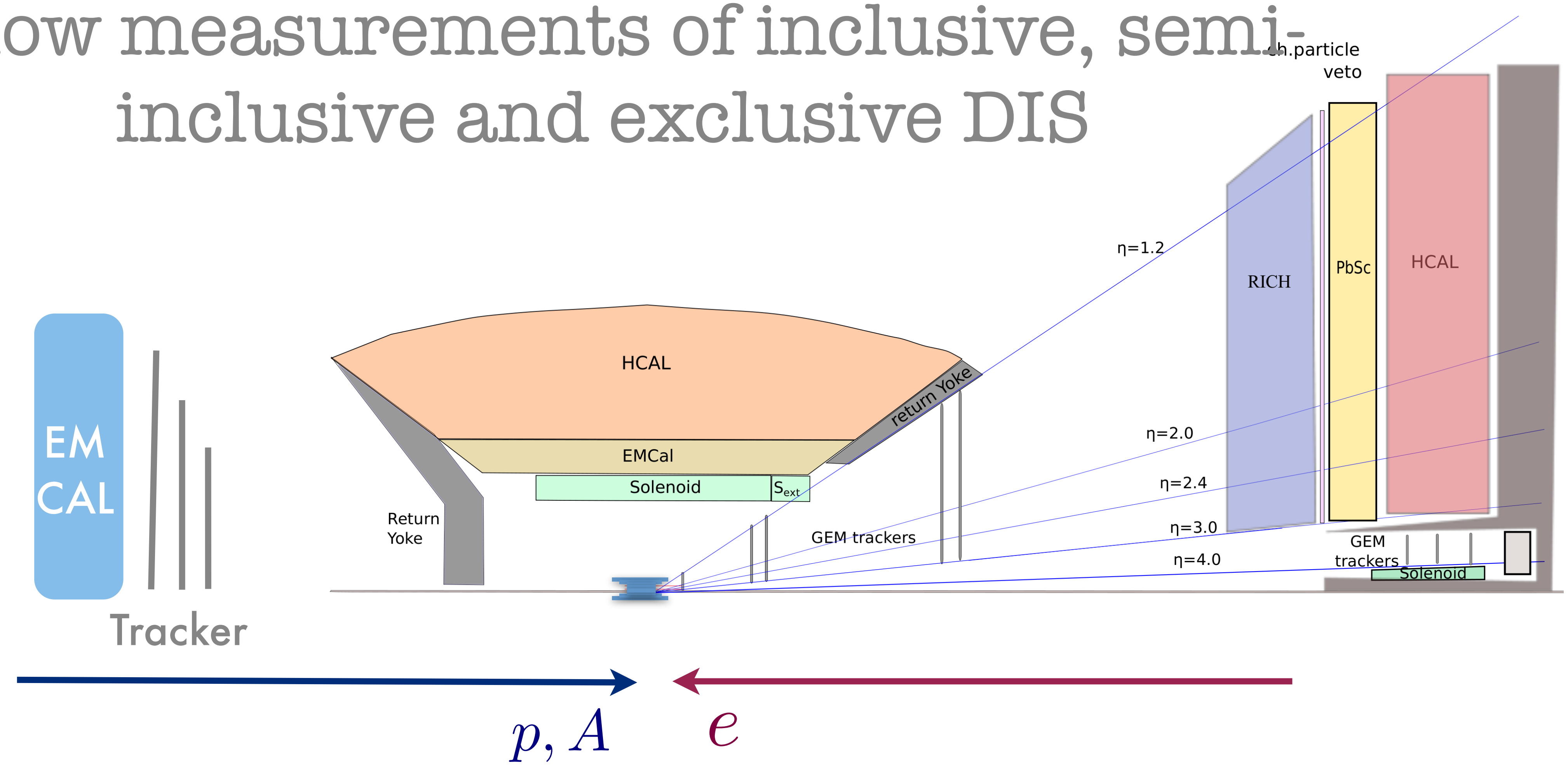
Allow measurements of inclusive, semi-inclusive and exclusive DIS



- The Forward sPHENIX spectrometer is being designed to be easily upgraded to a ePHENIX detector

ePHENIX

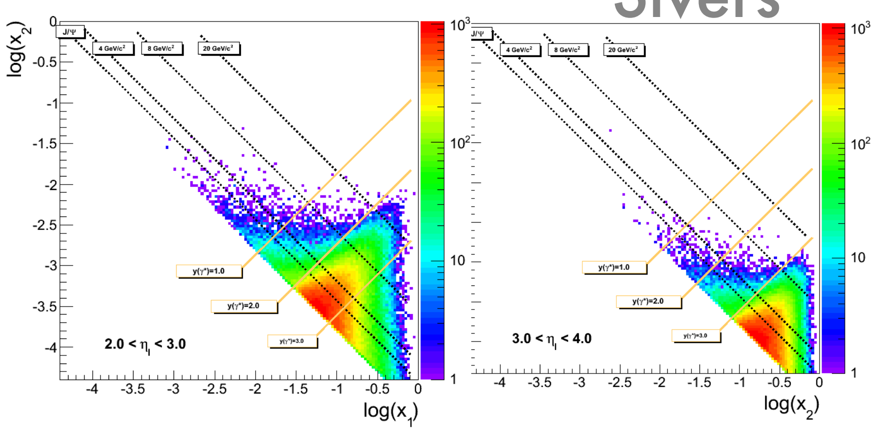
Allow measurements of inclusive, semi-inclusive and exclusive DIS



- The Forward sPHENIX spectrometer is being designed to be easily upgraded to a ePHENIX detector
- To detect the scattered electron, an additional tracking system and an EM-Calorimeter will replace the existing South muon arm

Outlook

Sivers



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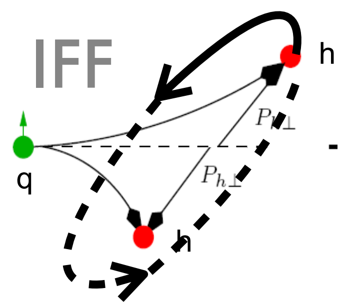
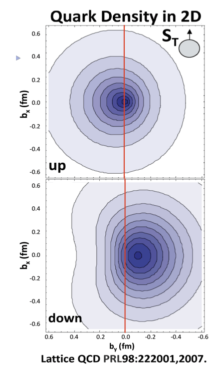
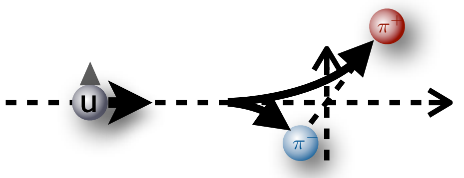


Sivers



Collins



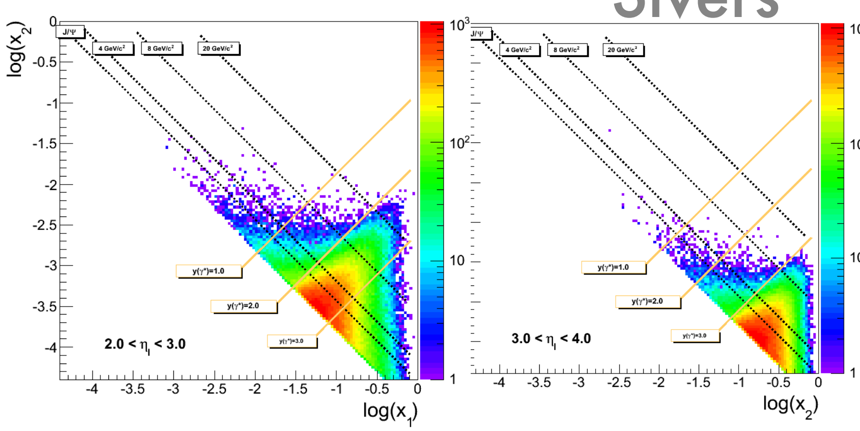
Boer-Mulders

Sea Transversity

Gluon Sivers

Outlook

Sivers



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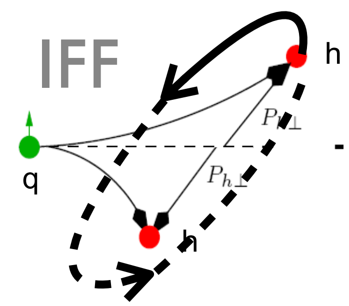

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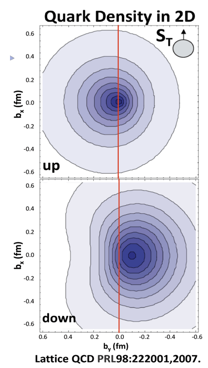

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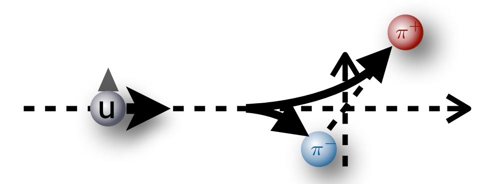


Boer-Mulders

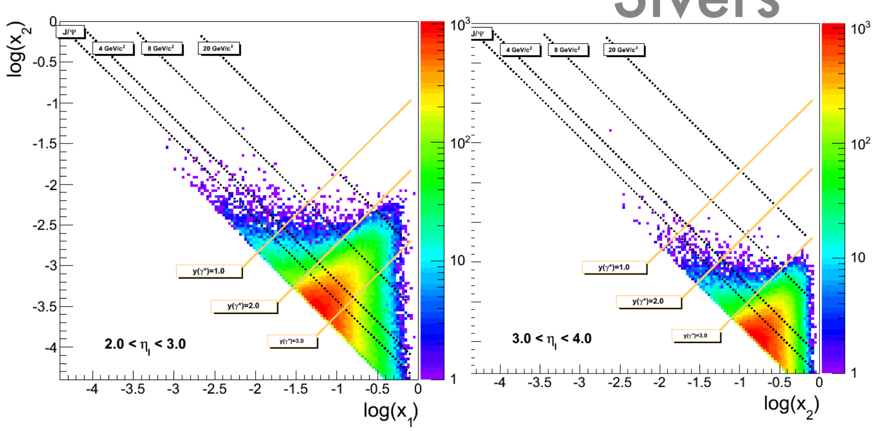
Sea Transversity

Gluon Sivers

- Detector detailed simulations in progress
- Dedicated R&Ds to start soon
- Funding possibilities under investigation

Outlook

Sivers



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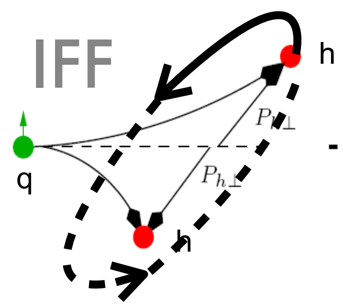
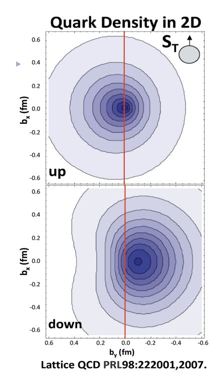


Sivers



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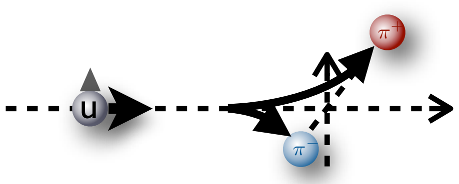

Boer-Mulders

Sea Transversity

Gluon Sivers

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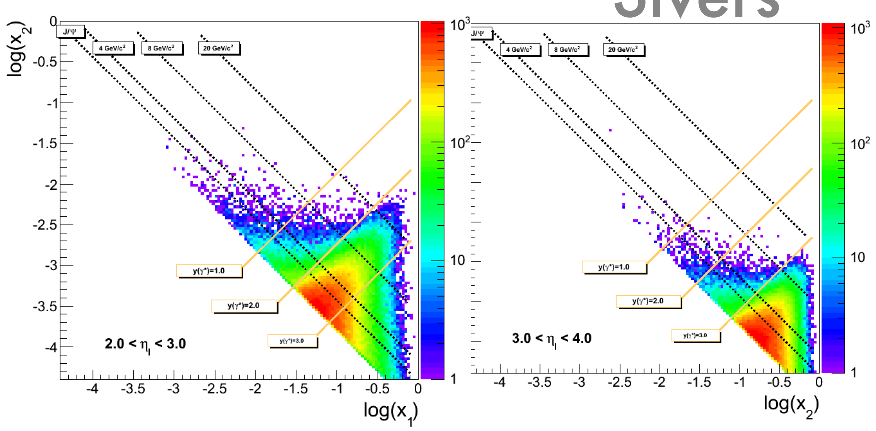
More collaborators welcome to join this interesting new project!

Outlook

Sivers



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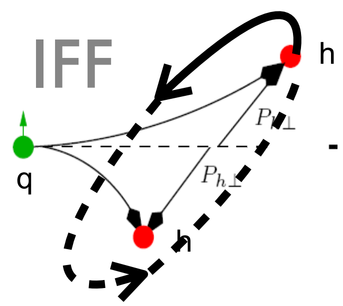

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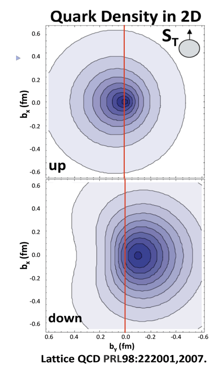

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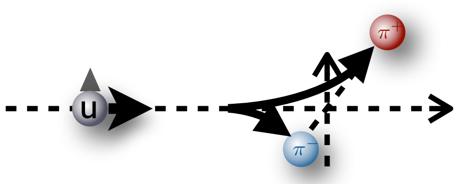

Boer-Mulders

Sea Transversity

Gluon Sivers

- Detector detailed simulation in progress
- Dedicat[illegible]d R[illegible] to [illegible]
- Funding possibilities under investigation

Thank you!

More collaborators welcome to join this interesting new project!